The Thesis Committee for Augusto Vitorio Tiezzi
Certifies that this is the approved version of the following thesis:

A Study of the Effectiveness of the Clear Flow Matrix in Building Construction Projects

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: _____
William J. O'Brien

Co-Supervisor: _____
John D. Borcherding

A Study of the Effectiveness of the Clear Flow Matrix in Building Construction Projects

by

Augusto Vitorio Tiezzi

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

August 2018

Dedication

To my beloved family in Brazil

To Lott Brothers

Acknowledgements

First and foremost, I would like to express my deep gratitude towards Professor Dr. O'Brien and Dr. Borcherding, my research supervisors, for their guidance, patience, availability and immense knowledge. Without them, this thesis would not have been possible. I would offer special thanks to David Lott and Wayne Lott from Lott Brothers Construction Company who gave me the opportunity to write my Masters' Thesis on this novel and interesting topic. Their vast experience in construction projects was pivotal to my research, from which I could learn and improve myself by a significant margin during my time spent with them while developing this thesis. I am grateful to everybody else from Lott Brothers Construction Company who assisted me in any way.

Furthermore, I would like to thank all CEPM faculty members, especially Dr. Caldas and Dr. Leite for giving assistance and advice since my first day at the University of Texas at Austin. I am also thankful for all my friends from Austin who welcomed me with true friendship and with whom I have shared some of the most unforgettable moments of my life.

Last but not the least, I am very grateful for my family in Brazil; my parents, my sisters, brother, niece, and nephew in particular for their immense love and encouragement in studying abroad while giving me endless support.

"Somewhere, something incredible is waiting to be known."

Carl Sagan

Abstract

A Study of the Effectiveness of the Clear Flow Matrix in Building Construction Projects

Augusto Vitorio Tiezzi, M.S.E

The University of Texas at Austin, 2018

Supervisor: William J. O'Brien

Co-Supervisor: John D. Borcherding

Cost overruns, schedule delays, and contractual claims are commonplace in construction projects. These issues often are the result of poor planning by the construction management team, or the improper alignment of field production management and control with the project schedule. To ensure that the schedule is properly executed in the construction process, the production management and control system must be manageable, intuitive and visually evident for all levels of management and trade supervisors. This need is especially critical for building construction, where client requirements often result in changing project demands, particularly for interior equipment and finishes. The various finish trades for a large building with many segments or floors may produce a large number of trade-location activities for the construction team to manage during construction. Thus, a good production plan is required to implement the schedule. Lott Brothers Construction Company has created a novel production management and control technique entitled, the Clear Flow Matrix (CFMx). The technique consists of a matrix integration of the trade activities and locations wherein time and workflow rhythm are represented through the progress of a unique Balanced Workfront, which balances client completion demand and trade contractor operations efficiency as trade work progresses through the building

areas. The visual nature of CFMx and the Balanced Workfront provides the project participants with a production framework for managing production and documentation of trade-exchanges so critical for quality completion of the work in accordance with the contract schedule. The thesis discusses the theoretical underpinning of the CFMx and how the embedded concepts are used to produce this visual matrix framework for production management and control to deliver the project in full alignment with the master schedule. The thesis provides several example applications of the Clear Flow Matrix to various types of building construction projects. Data collected from the applications through jobsite observations of the work (Work Sampling Analysis) and questionnaire interviews of trade contractor foremen and project managers provide insights into the effectiveness of the Clear Flow Matrix in comparison with other production management techniques currently used in the construction industry.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

PROBLEM STATEMENT

A construction project is a dynamic and complex system comprised of many different types of activities occurring simultaneously and/or sequentially all in accordance with a logical sequence. Because of the sequential nature of many project activities, a simple delay in one specific activity may cause serious and growing problems to cascade into the activities that follow the delayed one. This can result in an overall project delay; and the completion deadline may be much later than the original project completion date. In building construction, the process of planning, scheduling and controlling is complicated and ever-changing, especially for interior finishes. The building process requires the consideration of appropriate sequences to permit safe construction according to physical constraints of the site and the natural laws. Consideration of gravity, for instance, plays an important role, requiring the foundations and basements to be constructed before other structural elements. Moreover, interior finishes require careful management attention, so that the various trades can perform the work safely and with quality in the appropriate order necessary to complete the project. That is, trade workers from the several different subcontractors must pass through each room of the building and complete the work in the proper sequence at the proper time. Therefore, a good construction plan and its embedded production plan is fundamental to the successful execution of construction projects.

Since 1950, construction planning has been a topic for research resulting in new methodologies and techniques useful in planning, scheduling, production control of the work activities as well as overall management of construction projects. Among them, the Critical Path Method (CPM) has been adopted by the construction industry as a standard model for the scheduling calculations required to determine project completion dates under

a set of project and management circumstances. However, CPM scheduling software programs commonly available and applied to building construction projects present certain limitations for managing construction projects. One of the first authors to mention these limitations was Geroge Birrel. Some of his main critiques on CPM are as follows: it fails to handle resource allocation; ignores the workflow management of the project, making this technique incapable to maintain crew work continuity. The author also stated that CPM focuses on duration of activities and disregards the cost of the project (Birrell, 1980). Furthermore, CPM is represented using Gannt-Chart to track activities. This format is hard to understand, especially when projects have many activities, resulting in many pages of documents. As construction projects are dynamic and uncertain processes, the schedule needs to be updated on a regular basis. Therefore, using CPM, the schedule updating becomes a cumbersome process requiring significant amount of effort to replan. According to Henrich & Koskela (2006), one of the main reasons for construction delays and other failures is the construction industry´s widespread use of the activity-based scheduling tool as a paradigm for construction management, such as the CPM. So, if the CPM is not the most suitable tool to manage construction projects, what is a good plan?

MOTIVATIONS AND PURPOSE

Cost overruns, schedule delays, and contractual claims are common on construction projects. Poor planning is one of the leading factors for these failures. As stated before, experience has proven CPM to be a weak tool for scheduling and managing production. For this reason, in combination with the recognition of the value of Lean production techniques, engineers have adopted the same Lean thinking for the construction industry aiming for the improvement of project outcomes. This improvement can be achieved if

engineers implement a proper production system, which maximizes the amount of value and minimizes the waste of material, time and effort.

Many techniques are currently available for production control. However, each construction project is a unique and temporary production system. This brings up the question: are these various management tools suitable for different types of construction? The proper choice of construction management techniques is fundamental to overcome obstacles that arise within each of the diverse types of construction projects.

Bolviken et al. (2015) proposed a list of criteria for establishing a good construction plan including among others: tasks representation; use of time; use of space and fit to purpose. The authors also created a table to analyze techniques that encompass criteria for a good plan. From this table, it is worth highlighting how inefficiently activity-based CPM accounts for the use of space and resources in its common applications. However, the cause of poor planning in the construction industry comes not only from flaws of these different methods but also from the lack of commitment of all project participants. Furthermore, engineer's lack of knowledge about construction management theory can also contribute to the poor execution of engineer's management methods (Koskela & Howell, 2002.)

To ensure that techniques are properly executed in the construction process, they must be easily managed and intuitive. More specifically, it should be legible for trade supervisors and trade workers should focus on production, and should clearly present production flow through the project. The various finish trades for a large building with many locations (or many buildings and/or floors) results in a large number of trade/location/work activities that need to be controlled during construction. The production control method should be readily available for review and use at the work face, and suitable for implementation with or without digital technology.

Facing routinely with management problems in construction, the brothers David Lott and Wayne Lott from Lott Brothers Construction Company recognized this need of an intuitive tool to manage their projects. They created a production control system called the Clear Flow Matrix (CFMx). This tool consists of integrating the locations and crew activities into a true scheduling and controlling process. Encompassing theory of Takt Time, Location Based Management System and Last Planner System, this new technique balances resource efficiency and flow efficiency by effectively communicating the schedule status of all flow units under production at each takt time interval. This research will present data to assess the use of the Clear Flow Matrix in building construction projects.

RESEARCH OBJECTIVES

The main objective of this research is to evaluate the Clear Flow Matrix as a production control system for construction projects. Over the years, new management tools for construction projects have been launched in the marketplace. This thesis will also compare the new technique elaborated by Lott Brothers Construction Company, the Clear Flow Matrix, to others existing in the construction industry. The specific objectives include the following:

a) Through Work Sampling Analysis, the thesis will assess the effectiveness of the Clear Flow Matrix and compare its performance with the production rates achieved using more traditional scheduling and production control systems;
b) Describe the Clear Flow Matrix in its daily management process and compare it to other traditional techniques of construction management.

RESEARCH METHODOLOGY

This chapter shows an overview of methods and study data. The flow diagram presents the steps of this research.

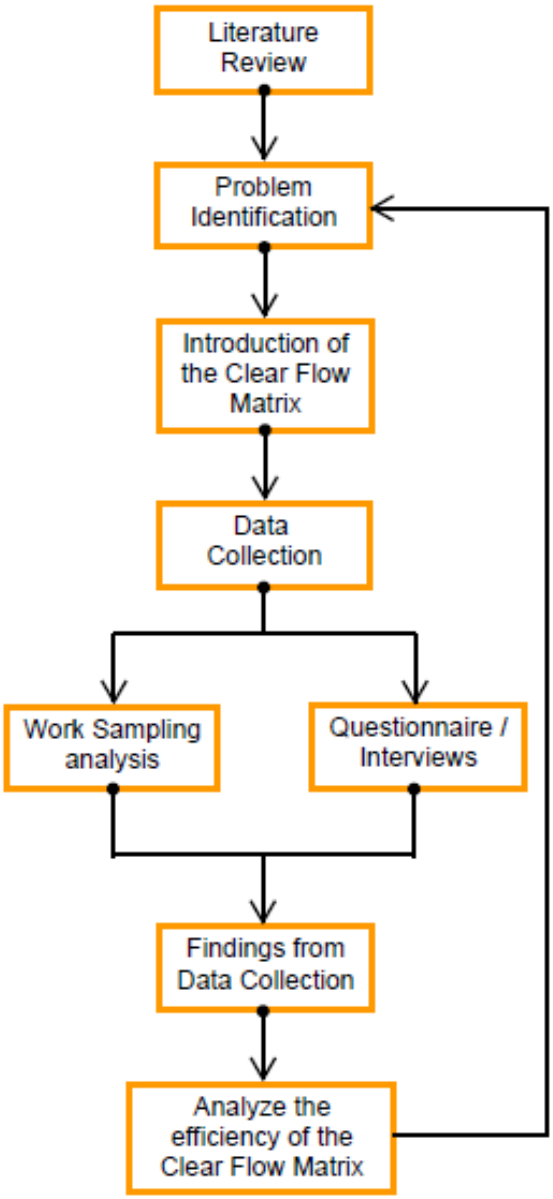


Figure 1: Thesis methodology

As shown in the flowchart above, this research begins with a literature review that will focus on production control systems for construction projects. The literature review will present an overview of construction project management and the main problems encountered in the construction industry. Moreover, this chapter presents some of the relevant topics related to the Clear Flow Matrix. In the next step, the thesis will introduce the technique elaborated by Lott Brothers Construction Projects to control production in construction projects: the Clear Flow Matrix. This section will present the history and background of the Clear Flow Matrix, how this technique works and how to apply it on construction projects.

Afterward, the data will be presented and discussed that was collected from job site visits. During the development of this research, job site visits were performed routinely on three projects in Texas. This research uses two methods for collecting data to be able to answer the objectives of the thesis. The first approach is the Questionnaires and Interviews with superintendent, foreman, and project managers of subcontractor companies, which have worked on projects that the Clear Flow Matrix has been used. Another data source is the Work Sampling Analysis. This method scrutinizes the amount of time in categories (direct work, idle, transport, personal, travel and instruction) that workers spend on job sites. According to (Parker & Oglesby, 1972) the Work Sampling Analysis measures the effectiveness of the management method used for construction. The results will be compared to a research conducted by Gong et al., (2010), which shows Work Sampling outcomes of projects from 1972 to 2008 performed in Texas. Thus, Work Sampling findings are valuable data to assess the Clear Flow Matrix.

After gathering all the answers of Questionnaires and Interviews, Work Sampling, these results will be analyzed. With the outcomes from those data, it will be possible to assess the effectiveness of the Clear Flow Matrix and verify if this new technique fills the gaps of construction management encountered in the literature review. Furthermore, it will enable a comparison study between the use of the Clear Flow Matrix and other construction management techniques.

Chapter 2: Literature Review

THE FAILURES OF CONSTRUCTION PROJECTS

In search of the literature, authors concluded that construction projects present severe failures, such as low rate of productivity, cost overruns, project delays and safety issues. Even with the emerging technologies that can be applied for enhancing construction processes—such as Building Information Modeling (BIM), Radio Frequency Identification (RFID), among others—and also with the introduction of better tools, machineries and materials which were launched in the market over the years, the improvements in the construction industry have minimally impacted the construction rates in some type of projects. One typical example that shows the almost flat progress is the productivity in multifamily new housing construction projects. As shown in the chart below (figure 2), since 1987 the productivity rate remained the same over the course of years. In case of multifamily projects, the productivity rate has improved but barely from 1987 to 2005. After this period, there was an improvement until an abrupt fall in 2011, which lasted for short period, following by an increase again till date (2018).

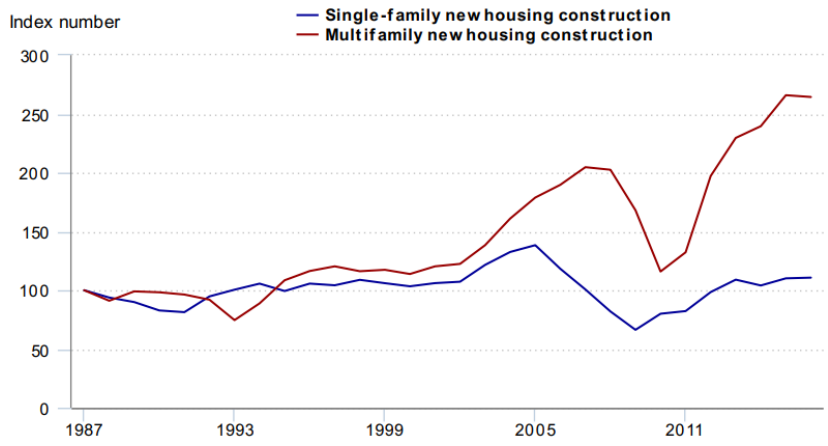


Figure 2: Index productivity (output per hour) in single-family and multifamily new housing construction, 1987-2016 (Source: Bureau of Labor Statistics)

The necessity of knowing the causes of the aforementioned failures is essential in contributing to the improvement of the construction industry. Henrich & Koskela (2006) pointed out five main factors that accuse production management as the principal agent for these flaws. These five factors are:

1. Lack of definite theory for construction and poor implementation of the few existing theories; however, the actual understanding of production management is divided into two main theories: Theory of Management, which is based on three other particular theories ("Planning," "Execution" and "Control") and Theory of Project, which consists of transforming operations. In his research, Koskela (2000) presented a new theory for production management, which includes "Flow" and "Value generation," named Transformation, Flow and Value Add Theory (TFV Theory). The next section will present more information about TFV theory.
2. As construction projects are temporary and unique, it is necessary to design a specific production system to perform each project. The development of a particular production system has great importance because it defines the workflow of the project and provides the requirements to perform activities, such as resources and sequence (Henrich & Koskela, 2006).

   In a broad perspective, construction works consist of a sequential process, in which each activity is performed individually in a logical sequence. Nevertheless, the reality is different, in which distinct activities can occur simultaneously in a parallel way (Bertelsen, 2004). Henrich & Koskela (2006) point out that without a proper production system the project tends to have more waste. This increase is because, in the phase of the design production system, the activities in the process should be analyzed to reduce waste as much as possible. Waste in construction is defined

here as any activity that takes time, resources and space but does not add to customer value (CII, 2005). Research has demonstrated that close to 30 % of the activities performed in construction projects add value (Seed, 2015). The construction industry presents eight main types of waste:

1) Overproduction – produces something before it is needed;

2) Unnecessary movement – movement of a crew that does not add value;

3) Waiting – Workers are not performing their jobs because they are waiting for something;

4) Unnecessary transport or conveyance;

5) Over-processing or incorrect processing - More processing that is required to produce customer demand;

6) Excess inventory – raw materials or work-in-process quantities that are higher than is needed for that moment;

7) Defects and Rework – products that are subpar or not in compliance with quality requirement standards and need to be repaired which in turn generates reworking;

8) Making-do – tasks are initiated without proper resources, such as tools, personnel, machinery, etc.

3. The use of activity-based methods, such as CPM and Line of Balance, as the primary tool for construction management. In construction projects, there are two types of scheduling. The first is activity-based scheduling, which is based on the activities duration and its dependencies (examples of this method are CPM, Critical Chain). The second is location based-scheduling, which assumes the same resource from each unit in multiple areas, such as Line of Balance. Both methods have their

weakness and strength. According to Henrich & Koskela (2006), a good production management system should at least give information of “What,” “Where” and “When” the activity must be performed. The activity-based methods do not give information of the three “Ws” at the same time. However, they can be complemented by other methodologies. The authors also argue that both methodologies (activity-based scheduling and location-based schedule) are not able to manage resources, which is essential for a reliable production control system. The necessity of having better tools which embrace not only scheduling calculation, but also the management of workflow for controlling construction projects is evident.

4. The use of the Push-System for production control. Construction projects have two types of production management; Push-System and Pull-System. The Push-System does not consider the actual status of the project. This means that this system controls the project, releasing works, information, and resources, based on a plan (Kalsaas et al., 2015). Moreover, the Push-system considers that all resources needed to perform the tasks are currently available (Tommelein, 1998). On the other hand, the Pull-Systems is considered in the context of Lean and is often associated with Just-in-Time production. This system releases the work according to customer demand, assuming the actual status of the project. The main characteristic of Pull system is the downstream work process, which the production plan is based on the target completion date. Koskela & Howell (2002) pointed out the importance of the Pull System in “ensuring that all prerequisites are available for the assignments.” One classical example of Pull-System in construction is the Last Planner System. Henrich & Koskela (2006) argue that construction managers

tend to use the Push-System more, which is aggravating for the construction industry. The table 1 below presents some differences between the systems;

PUSH SYSTEMS	PULL SYSTEMS
Schedule releases the work	Costumer demand releases the work
Based on market focus	Based on client focus
Stock pilling	Just-In-Time
Inflexible	Flexible
Value is implicit	Pressure for higher value

Table 1: Comparison between Push and Pull Systems, adapted from Henrich & Koskela, 2006

5. The lack of commitment of all project participants. In construction projects, most of the works come from subcontractor companies. As their primary focus is profit, usually these companies try to finish their work as soon as possible and move to another contract to avoid idleness, not considering the optimal pace of the work. This situation leads to waste because many times the activity is not ready to start due to lack of resources, or because space is not ready since the prior trade is still working in the same spot. Furthermore, usually only project managers from contractors participate in the scheduling process, and the specialist operations (subcontractors), who may have the most experience, usually do not take part in it. Moreover, the subcontractors may not have access to the schedule of the project, receiving from contractors information only about the start dates and finish dates.

Research by Zhang et al. (2005) also indicates that production management is the main problem in construction projects. The authors conducted a survey asking expert

residential construction managers to rank the main factors that impact productivity and waste reduction. The scale used ranged from 1 (no influence) to 5 (major influence). The results of this study showed that "planning and control" is the primary factor to reach project success with the average of 4.9. The second most important factor is "communication and coordination" with an average of 4.7, followed by "labor" (availability, skill, motivation, etc), "equipment and tools" (appropriateness, quality, etc).

It can be concluded that most of the items cited above which accuse construction management as the principal motive for project failures are related to human aspects. It means that the complexity of the construction works is not the only barrier to make the project successful. The lack of commitment of all project participants involved in the projects, where subcontractor's experts rarely participate in the scheduling phase, also leads to unsuccessful project outcomes. Moreover, the existing techniques of construction management are either not still efficient or are not being properly applied due to some difficulty. These include easy visualization and interpretation to forecast possible problems and the cumbersome work to track and update the activities. The need of a reliable production system, which takes into consideration workflow and in which every project participant (from the bottom line to the board) can understand, is vital for the construction industry.

TRANSFORMATION, FLOW AND VALUE GENERATION THEORY

As mentioned in the last section, the theory of project adopted the only transformation as a concept for production systems. In 2000, Koskela developed an extension of the theory of production by adding two more elements: Flow and Value Generation (theory known as TFV). Although the flow concept had been used before by

Lean philosophy, the TFV Theory assumes that flow, transformation and value generation must be considered together and balanced (Bertelsen & Koskela, 2002). A brief definition of these three terms is presented below.

Transformation in the context of production is any activity that uses input (resources and information) and transforms them into products to the customer (output). In other words, transformation is an input-output process and can serve as an instrument to find out which tasks are needed in the project (Koskela,1999). In construction, one typical example of transformation process is pouring concrete. The raw materials that compose concrete (for instance, cement, sand and others) are transformed in a final product (for example, slab on grade). For that, many activities must occur during the transformation stage. So, transformation is associated with tasks. The figure 3 below represents a scheme of transformations in production systems.

Figure 3: The concept of transformation in production management

Flow can be considered any movement in the production system and flow is an addition of three more stages to transformation process: waiting, inspection and movement (Bertelsen & Koskela, 2002). Production system started to consider flow when project managers assumed time as an input element. The input time regards not only the duration to perform the task (transformation), but also the time spent between transformations which is considered as waste.

A fundamental improvement to minimize waste in production systems is to shorten the throughput time by eliminating non-value activity. The throughput time is the period that the product takes to traverse the four elements of flow (Figure 4). By reducing the waste time, it also reduces the non-value activities. Some procedures may lead to this improvement, such as decreasing the rework, elimination or reduction of inventories and reducing the distance between workstations (Koskela, 1999).

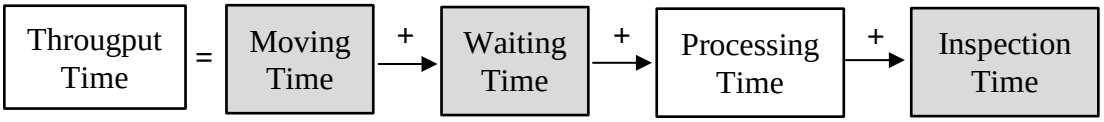


Figure 4: Flow process in a production system. The gray box represents non-value add activities (adapted from Koskela, 1999).

According to Koskela (1992), construction projects are composed mainly of design flow process and construction flow process. The construction flow process is divided into two main categories:

1. Material Flow: This is the movement of material from the factory to the job site (supply chain) including processing and assembling on site. One example of this type of flow is the assembly of Heating Ventilation and Air Conditioning (HVAC) ducts. The factories produce the ducts, which are delivered to the construction site. Once the ducts arrive on site, they are transferred to the location of installation and are installed.
2. Location Flow: This type of flow in construction is the movement of the workers through different locations of job sites (workstations). Location flow is a good example that demonstrates some discrepancies between manufacturing and construction production systems. The locations flow in

manufacturing is the movement of the product, while in construction it is the workers. Taking the prior example of the ducts installation task, when the ducts are in their correct places, workers must move from workstation to workstation to install them.

Koskela (1999) states that construction projects consist of multiple operations, which require many types of input flows. The author pointed out that seven resource flows are needed to generate transformation (task). For that reason, production systems must consider flows and transformation at the same time so that workstations will contain all the required resources for tasks to be performed. The figure 5 below shows the seven input flows defined by Koskela.

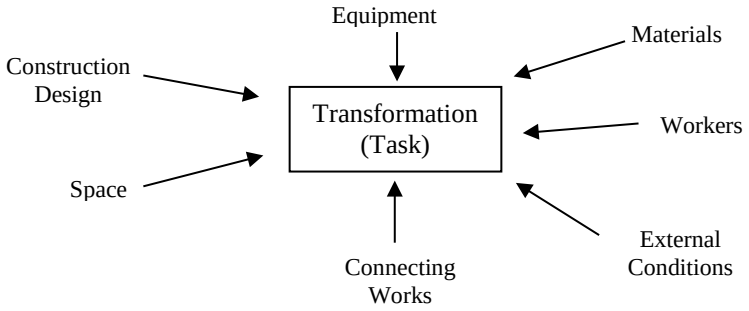


Figure 5: The seven inputs flows for construction task (adapted from Koskela, 1999)

The last element of the TFV Theory is value generation. This phase occurs when the final product is delivered to the client. In other words, the goal of production is reached satisfying customer needs.

In the table 2 below , Bertelsen and Koskela (2002) summarize the elements of TFV theory.

	Transformation view	Flow view	Value Generation View
Concept	Transformation of input to output	Associated with any movement of material in the production system composed by moving, waiting, processing and inspection	The final product is delivered to the client. The customer needs are fulfilled.
Principles	Decompose the production in different tasks; control of decomposed activities	Eliminate the non-value adding activities (non-transformation activities); reduce variability	Make sure that all the customer´s requirement are met. Ensure the capability of the system
Methods and Practices	Work breakdown structure (WBS)	Pull System (Last Planner System)	Quality function deployment

Table 2: A summary of TFV Theory (table adapted from Bertelsen & Koskela, 2002).

FLOW IN CONSTRUCTION

The TFV Theory from Koskela proposes a new production concept for the construction industry. Among the three items of his theory, it is valuable to focus more on the "flow." "Construction Physics," a paper elaborated by Bertelsen et al. (2007) presented a new perspective of construction processes, in which the core is the construction flows. To develop the idea of Construction Physics, the authors based the work on Hopp and Spearman´s paper, the "Factory Physics", which considers flow, queuing theory, and variability to understand the mass production concepts.

To go more in-depth about flow in construction, it is first necessary to understand what flow is in production systems. The Cambridge Business English Dictionary defines

"flow production" as the same as "continuous production," that is "a manufacturing process in which finished products are made from basic materials in one continuous process without interruption." In manufacturing, this definition is more straightforward to understand than in construction. In factories, products usually follow a production line, moving from workstation to workstation; resources, for instance, workers, transform the raw materials into final products. This type of production system is analogous to a fluid that flows in pipes. The fluid is the product and pipes represent the location of workstations.

Shingo (1989) defines production systems as a chain of events that combines two types of flow: the process flow and the operations flow. He clarifies the difference between them through a two-dimensional chart, where the vertical axis is the process flow, and the horizontal axis is the operations flow (figure 6 below).

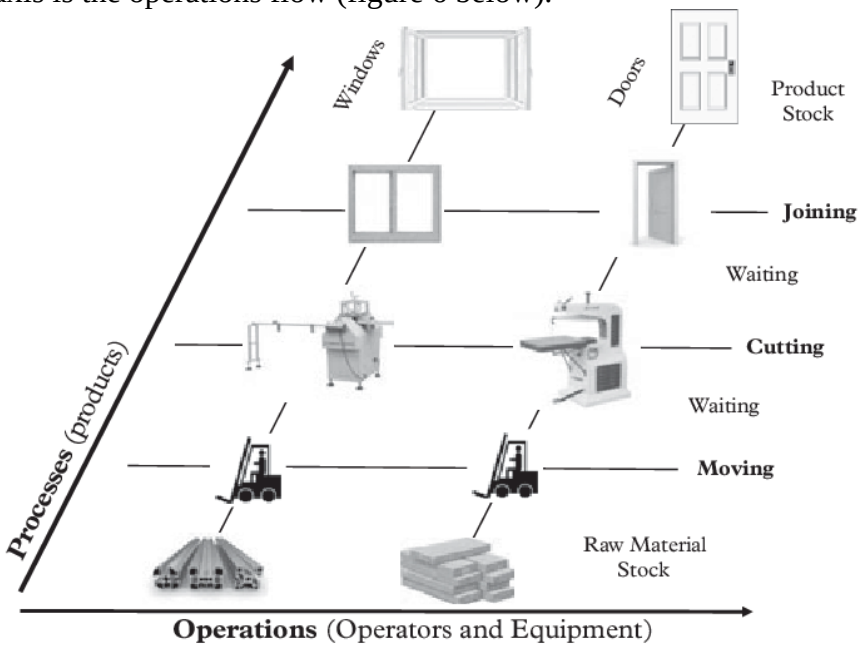


Figure 6: Scheme of operations and process in production systems (Sacks, 2016)

The process flow is the transformation of raw materials into products. The objective of this flow is the delivery of value to customers, which consists of four steps: processing, inspection, transport, and storage. These steps are almost the same of Koskela´s flow definition when he pointed out that flow lies on moving, waiting, processing and inspection. The operations flow represents the worker activities and the machine activities with the raw materials (Shingo, 1989). These actions are the equivalent of tasks, which are associated with the transformation of TFV Theory from Koskela (Sacks, 2016).

Shingo (1989) says:

> When we look at process, we see a flow of material in time and space; its transformation from raw material to semi-processed component to finished product. When we look at operations, on the other hand, we see the work performed to accomplish this transformation – the interaction and flow of equipment and operators in time and space. Process analysis examines the flow of material or product; operation analysis examines the work performed on products by worker and machine.

On the other hand, as in construction job sites, the physical movement of products in a line does not occur, as exemplified in manufacturing. The term "flow in construction" is hard to visualize. The analogy with fluid flowing thru pipe presented above for manufacturing is not suitable here for construction, in which many activities occur simultaneously and not in a single sequence. Moreover, in construction projects, products are fixed to the ground, making it necessary the movement of workers through different locations instead of products (Kaalsas & Bolviken, 2010). Flow in construction embraces both physical flow (material, equipment, and crew) and non-physical flow, such as the flow of information. Bertelsen et al. (2007) and Koskela (1999) point out that construction processes consist of multiple flows. Sacks (2016) associated construction projects with "very jumbled flow; process segments loosely linked." Therefore, the visualization of workflow in construction is not as straightforward as in manufacturing.

It can be noted that two different authors from distinct industries, Shingo in manufacturing and Koskela in construction, have very similar views, in which both assume flow as an essential component in production systems. Despite the discrepancies between the two industries, the two types of flow defined by Shingo—process, and operation—are also seen in construction projects. The progress of work, when areas of the job site are converted into the final product, correlates to the process flow. For instance, to build a kitchen in a house, many processes are necessary to reach the final product, such as structural frame installation, MEP (mechanical, electrical and plumbing) rough-in, drywall, etc. On the other hand, crew activities moving from spot to spot are the operations flow.

The construction industry has the tradition of focusing more on operations flow rather than on the process flow (Bertelsen et al., 2007). This means using resources as much as possible has been the conventional way to improve efficiency in construction projects. However, by the introduction of Shingo´s production concept, it is clear that focusing only on process flow or operation flow does not enhance the system as a whole. Both flows need to be efficient and balanced. The improvement of process flow occurs by reducing as much as possible non-value adding activities, which are moving, waiting, and inspection. Balancing the workers and improving the tools and methods are ways to enhance the operations flow (Sacks, 2016). Koskela (1992) identifies eleven main principles that lead construction to a proper flow:

1) Reduce waste a much as possible;

2) Reduce the throughput time;

3) Reduce variability;

4) Simplify the process as much as possible, decreasing the number of steps;

5) Have flexibility;

6) Have clear communication and transparency;

7) Focus control on the complete process;

8) Build continuous improvement into the process;

9) Balance flow improvement with conversion improvement;

10) Benchmark;

11) Increase the output value considering the customer requirements.

The idea of good flow applies to any production system. Womack and Jones (2003) state that the production system must have the minimum possible non-value adding activities to achieve a good flow. In construction, rework is a classic example that leads to discontinuous workflow. Also known as adverse flow or re-entrance flow, rework occurs when trades need to return to the previous location, where they have already worked, and do the work again. Trades usually have to remove or demolish the defective structure or component. This happens due to some common causes, such as damages provoked by other trades, work not well-performed, project scope changes, design changes, fabrication errors, among others. Re-entrance affects the workflow, not only the trade that has to do work again but also the subsequent trade, which will become idle waiting for the area to be ready. Therefore, rework correlates not only with the process flow by extending the cycle times of the area, but also impacts the operations axis, by causing discontinuous workflow and idle time (Sacks, 2016).

Shingo presented his concept of process, and operations flow based on manufacturing industry, where companies deliver individual products (Sacks, 2016) and workers belong to only one organization. On the other hand, the construction industry produces projects (Sacks, 2016). Furthermore, construction job sites usually have many subcontractor companies that remain with the projects for a certain period and then move

to other contracts. Taking into consideration these particular differences between construction and manufacturing, Sacks (2016) tweaked Shingo´s idea for construction projects, creating the PPO model (Portfolio, Process, and Operations). The PPO considers a three-dimensional model of the Process and Operations chart from Shingo. The Portfolio axis represents the flow of works in different locations through different contracts. The figure 7 below depicts the three-dimensional PPO model, in which the vertical axis represents the portfolio.

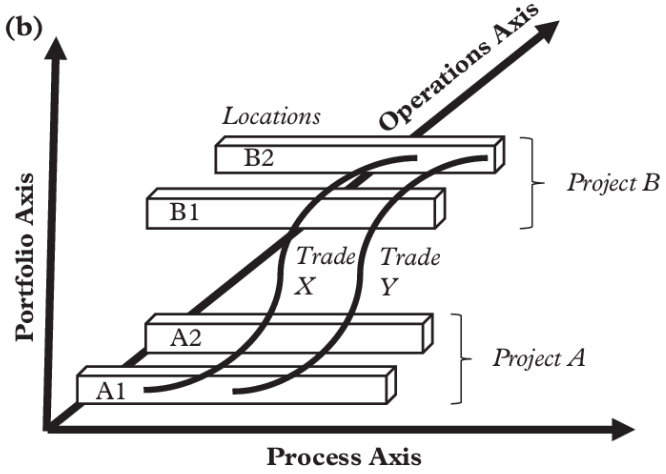


Figure 7: Scheme of flows in construction projects (Sacks, 2016)

Sacks (2016) correlates these three axes of PPO model with the primary management functions of job sites. The author points out that project managers focus on the portfolio axis, where they conduct simultaneously various contracts with suppliers and subcontractors. The site superintendents centralize their work on the process axis, where their focus is to finish the work areas so that the project can advance. Lastly, the operations flow axis represents the subcontractor trade manager, where they focus on high productivity and on utilizing their resources as much as possible. It is also worth

highlighting that the Portfolio axis is meaningful not only for construction companies but also for subcontractor trades, which have often-simultaneous contracts. Subcontractor managers need to manage their resources across these different projects to achieve a continuous workflow.

Sacks (2016) presented two types of the relationship among process, operations, and portfolio: the hierarchical and the cyclical. As shown in the figure 8 below, the hierarchical model assumes projects independent of each other, and the relationship between portfolio and operations does not exist. It means in practice that crews will work only on one project. This is not an ideal situation proposed by Sacks because it can cause idle time for workers. On the other hand, the cyclical model enables the creation of an ideal condition for optimal flow where workers can work on different projects simultaneously. This situation avoids gaps between projects and provides a steady job to their workers.

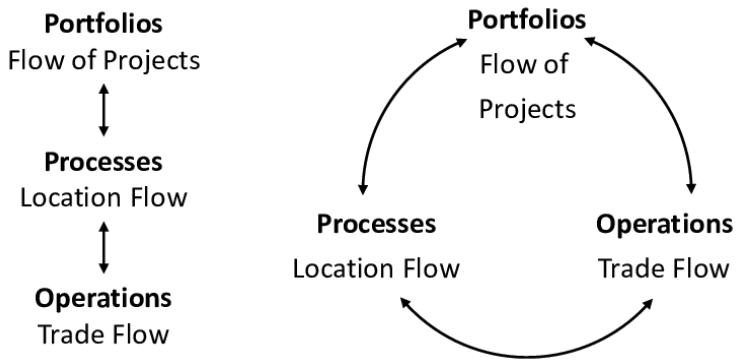


Figure 8: Hierarchical (right) vs Cyclical (left) model proposed by Sacks (2016).

The PPO model can be applied not only for shifting workers through different contracts but also for relocating any type of resources across various simultaneous projects. It is still common in construction projects to have poor site conditions and schedules changes, so resource allocation becomes a necessity for trade contractors to

achieve high productivity. However, according to O'Brien (1998), the link between productivity, type of resources and site conditions is the factor that determines the capability of trade contractors to allocate their resources. In construction projects, contractors have the responsibility to manage projects. They should impose the sequence and the rhythm of activities that will be performed; however, trade contractors are accountable for determining the amount and type of resource they need to allocate for the project. It means, that contractors cannot coordinate resources that subcontractors should employ (Birrell, 1980).

O'Brien (1998) defines resource allocation in irregular blocks based on the demand of each project, in which blocks represents one project. This representation of resource allocation is shown in the figure 9 below. Moreover, trade contractors usually work in one area at the same project and then move to another. This local allocation within one single project is also depicted in the chart below as a dashed line perpendicular to the time axis, which is seen here more frequently than in different projects (O'Brien, 1998). The dashed line paralel to the time axis represents the trades contractors working in many locations within a project at the same time.

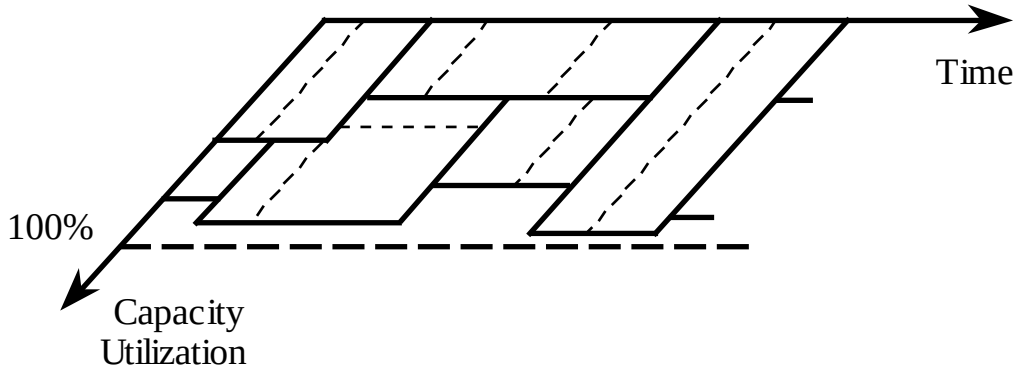


Figure 9: Representation of subcontractor’s resource allocation within different projects and in one project. (O’Brien, 1998)

EFFICIENCIES IN PRODUCTION SYSTEMS

In 2016, Modig & Åhlström (2016) presented a new perspective of production systems, which consist of resource efficiency and flow efficiency. However, this new concept is analogous with Shingo´s view and TFV Theory from Koskela. Like the Shingo´s chart of process flow and operations flow, two axes can represent the two types of efficiencies. Modig & Åhlström (2016) describes that resource efficiency represents how much the system is using resources over a period. Efficient use of resources has been a synonym for production efficiency. Therefore, for many years, the industry has adopted the concept of maximizing, as much as possible, the use of resources to increase the productivity and minimize cost as well. Once workers, equipment, and tools have high costs in production systems, it makes sense to keep these resources employed the entire day. Resource efficiency is related to operations flow from Shingo.

As described in the previous section, the industry has adopted flow as an essential component in its production system. Production flow refers to throughput time, which is the time needed for a unit to pass through all workstations from the beginning of the job to the end when the product is done. During this period, the product will be moved, inspected, processed and will be idle. Differently, from resource efficiency, which targets the maximization of the use of resources, flow efficiency focuses on the time of flow units processed in a production system. The meaning of flow efficiency is the capacity of generating valuable time during the throughput time. Modig & Åhlström (2016) defines flow efficiency as “a sum of value-adding activities in relation to the throughput time.” Flow efficiency requires the minimization of waiting, moving and inspecting, which are periods in production system that do not add value. The Shingo’s idea of process flow represents exactly the flow efficiency axis. Therefore, to improve the flow efficiency, the

system needs to increase not only the speed of the value-added activities but also increase the density of value transfer by eliminating waste. The formula below expresses the flow efficiency (Wernicke & Ledelow, 2016):

$$Flow\ Efficiency = \frac{\sum Value\ added\ times}{Throughput\ time}$$

By recognizing the difference in the dependence between the forms of efficiency, one can better understand the concept of the two forms. Resource efficiency has the intention to provide as much work as possible to workers, making sure that each resource will have a flow unit to process. On the contrary, by providing products with workers for flow efficiency, one ensures that each flow unit always has resources working.

Regarding value added, the primary characteristic of these two types of efficiency consists of providing and receiving. High resource efficiency implies a high percentage of value adding time by resources. High flow efficiency represents a high percentage of value receiving time to flow units from resources. One example that demonstrates poor flow efficiency in a construction system is when an area is ready for the next trade to work on it, and nobody is working (the area is idle). In construction of buildings, each area (for instance, kitchen, bedrooms, etc) is associated with flow units in production systems, in which each will receive added value activities by crews. However, in construction, flow units do not move through the process; they are stationary. The analogy of poor resource efficiency in construction is straightforward. A high percentage of idle time for construction workers on the job site represents one example of poor resource efficiency.

Between flow and resource efficiency, which one makes the system more productive? As previously pointed out, the industry has assumed resource efficiency as the

leading form of efficiency. However, to meet the customer needs, production systems must have both in process. The ideal situation is that both forms of efficiencies are combined in a high utilization. But, to achieve this circumstance is a difficult task, if it is not impossible, (Modig & Åhlström, 2016). Modig and Ahlstrom mention that the processes in production systems are operated according to particular laws. Three of these laws can explain the difficulty of balancing both types of efficiency in an effective way, which are: Little´s Law, the law of bottlenecks, and the law of the effect of variation on processes.

LITTLE´S LAW

John D. C. Little elaborated the Little´s Law theory in 1961. This theory says: "The average number of customers in a system over some interval is equal to their average arrival rate, multiplied by their average time in the system." A simple equation can represent this statement:

$$THR = \frac{WIP}{THT}$$

THR = Throughput rate**.** This is the average output per unit time.

WIP = Work in process. This is the quantity of units or customers in the production system.

THT = Throughput time. The average time that a flow unit stays in the system.

The throughput time of a unit is determined by:

$$THT = \sum flow\ unit\ \times cycle\ time$$

Cycle time represents the pace of flow units in the process and is the average time between two flow units.

By the equation above, the Little´s Law demonstrates that two factors directly affect the throughput time in a production system: Flow unit and cycle time. It means that the

throughput time increases if any of these two factors also increases, and consequently, the throughput rate (capacity) will decrease. The law demonstrates that if the production system increases the number of flow units to be processed, the throughput rate will decrease. Therefore, the capacity of the system is inversely proportional to the quantities of flow units.

As indicated earlier, to achieve a high resource efficiency in the system, it is necessary to have all the resources occupied as much as possible. This situation may occur with the implementation of buffers of flow units to resources, ensuring that resources will always have flow units to work in. Thus, a paradox arises with the Little´s Law theory. High resource efficiency requires insertion of buffer of flow units to avoid resource idleness. However, the Little´s Law states that with the increase of flow units in the production system, the throughput time also increases, and consequently the throughput rate (capacity) will decrease. A higher throughput time leads to a lower flow efficiency. This demonstrates that if the system wants to increase the resource efficiency by inserting buffers of flow units, the flow efficiency will decrease.

THE BOTTLENECK LAW

The Bottleneck Law was first mentioned regarding the Theory of Constraints of Dr. Eliyahu Goldratt, discussed in his book *The Goal,* 1984. The Bottleneck Law states that a system (say of production), regardless of how well it works, has at least one constraint (a bottleneck) that limits the performance of the system at any given step of the system.

A Bottleneck in any production system is the process step requiring the longest cycle time in the system operation, thusly determining (by constraining) the throughput rate (capacity) as described in Little´s Law. The Bottleneck Law states that a bottleneck

lengthens the throughput time of any production system. The identification of bottlenecks is vital in production management and control so that any identified bottleneck may be eliminated to maintain or improve the production capacity of the system. Two key factors characterize the presence of a bottleneck in any system: The increase of inventory immediately before the bottleneck and the low utilization rate of activities in the stage following the bottleneck. Some techniques commonly employed in system management to remove a bottleneck include, among others, adding more resources or increasing the speed of machine (or production) operations. However, once a bottleneck is identified and eliminated, it will appear in another place.

THE LAW OF VARIATION ON PROCESS

Variability in construction projects is very common and impedes good performance by creating uncertainties and unexpected conditions. Management strategy plays a relevant role on construction variability. Poor management can lead to needless changes resulting in increased variability in projects (Thomas et al., 2002). On the other hand, a proper implementation of management techniques can promote a reliable work plan which is one way to avoid or reduce unexpected conditions.

Three sources in production systems can have variations: Resources, flow units and external factors. Resource variations in construction, for instance, relate to different efficiencies encountered among workers. While some work at a fast pace, others are slower. Even machines and equipment can also have variations because they are prone to break down. Flow unit variations consist of different amounts of work in that particular station or area. Different workspace areas, for instance, kitchens, bedrooms, offices, are examples of these variations in construction projects. These areas require a distinct amount

of manpower and time to be complete. External factor variations in construction can be change orders and weather conditions, which affect the most when the project has not yet achieved the dry-in milestone.

The implementation of Lean thinking in the construction industry provided a new approach to deal with variability in projects. Lean strategies have been targeted with regard to continuous workflow and reducing throughput time to achieve high performance. As mentioned earlier, the throughput time defined by Koskela is the period that the product takes to traverse the four elements of flow, which are waiting time, process, inspection and moving time. The law of variations states that variabilities in production systems negatively affect the flow efficiency by increasing the throughput time and hamper the combination of high resource efficiency and high flow efficiency, (Modig & Åhlström, 2016). This raise of throughput time occurs due to the amount of waste generated in the process.

The relationship between variations and resource efficiency explains the primary influence of variations in production systems. As stated earlier by Little´s Law theory, the chart below (figure 10) illustrates that as the system improves the resource efficiency, the throughput time also increases. However, the variations law shows that the throughput time varies in an exponential curve as the resource efficiency also varies.

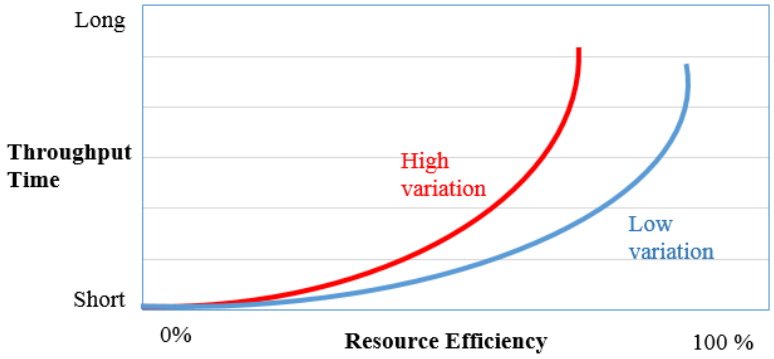


Figure 10: Influence of variations in the relationship between throughput time and resource efficiency (adapted from Modig & Åhlström, 2016)

Another important piece of information from the chart above is the influence of variations in the relationship between resource efficiency and throughput time. The curve with higher variation shifted to the left. This displacement means that with the same resource efficiency, the throughput time is higher for the curve with the high variation.

THE EFFICIENCY PARADOX

The previous sections demonstrated three laws, which point out some factors that impede production systems to improve flow efficiency. These negative factors mainly occur due to the increase of throughput time. As mentioned earlier, flow efficiency is the relationship between value-adding activities and the throughput time. The first law, Little´s Law, proves that as the flow units increase in the system, the throughput time will also increase, resulting in lower capacity. The second law, the bottleneck law, states that bottlenecks increase the throughput time of the system. The last law, the law of variations on process, asserts that variations negatively affect the system by raising the throughput time. In sum, five components alter the flow efficiency: variation, the number of flow units, resource efficiency, bottlenecks, and cycle time.

The paradox appears here when trying to improve resource efficiency by adding flow units. This action may generate bottlenecks and variabilities, decreasing the flow efficiency. Furthermore, Little's Law shows that more flow units means less flow efficiency. It can be concluded, then, that the complex and non-linear relationship between project flow efficiency and project resource efficiency provides a management paradox that is difficult, if not impossible, to optimize for each type of flow, (Modig & Åhlström, 2016).

As mentioned earlier, companies tend to utilize as much as possible their resources to be more productive. However, the paradox says that it will not improve the system as a whole. This brings up the question: is it possible to solve this paradox? The answer is to focus on flow efficiency (Modig & Åhlström, 2016). Organizations can enhance the flow efficiency by decreasing the throughput time of the system. As stated by Koskela (1992), eliminating unnecessary work, which does not add value, or simplifying the system to increase the speed of the work, are ways to do so. Rework is a classic example of a barrier that impedes high flow efficiency in the construction industry. As construction projects have different trades working on, the handoff process between trades needs to be fast and smooth. Any type of disruption, such as rework, hinders the continuous flow. Waste, in general, is the biggest hurdle to achieve high flow efficiency. One strategy to solve the efficiency paradox is Lean, which the elimination of waste is of its central tenets.

THE EFFICIENCY MATRIX

Modig & Åhlström (2016) uses a matrix to represent different operation states of an organization in regard to flow and resource efficiency. As shown in the Figure 11 below, the matrix has four distinct operation states. The number one area consists of a stage that

is the most common in the industry, in which the system has high resource efficiency and low flow efficiency. This stage represents a project in which workers are using resources, but the customer is not receiving value at an appropriate rate. Another representation of this area is the vast amount of inventory between workstations. The Little´s Law explains one possible cause of this situation, which is the insertion of buffers of flow units. The area number two is the worst scenario, where the company is neither resource efficient nor flow efficient. The reduced utilization of resources, such as idle workers and low rate of value generation to customers, are characteristics of this stage. The area number three is not typical in the industry, which has high flow efficiency and low resource efficiency. This stage represents an organization that focuses on customer demand and not in resource utilization. The last stage, the number four is the ideal situation, where the system has high flow efficiency and resource efficiency at the same time. As explained earlier, this stage is hard to reach.

The star point in the Figure 11 below is the perfect state when the production system combines flow efficiency and resource efficiency at high utilization. However, the achievement of this point requires two essential factors. The first one concerns predictability of flow efficiency, which is the necessity of knowing the perfect customer demand in the present and the future so that the rate of production (capacity) meets precisely the customer needs. This eliminates waste such as inventory and waiting time. The second element refers to resource efficiency, which requires flexible and reliable resources so that they can be adjusted according to the variations of customer demands.

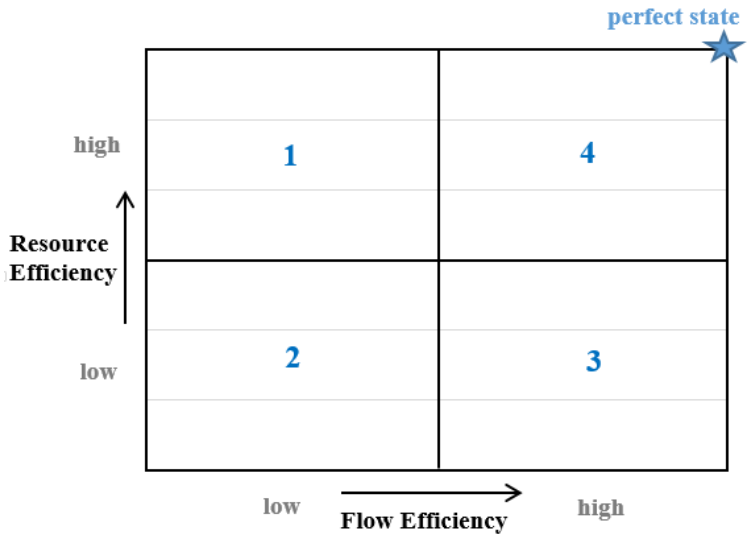


Figure 11: Four operations states of organizations (adapted from Modig & Åhlström, 2016).

Variations hinder the efficiency of the production system as a whole. Variations on resources and flow (customer demand) will determine which of the four stages mentioned above the system will operate by creating the "efficient frontier," (Modig & Åhlström, 2016). The efficient frontier is a line that represents a limit of efficiency that the system can operate. It means that the positions of organizations status can be somewhere within this limitation, but the location is also dependent on the priorities of organizations. The chart below represents the influence of variations on the four stages of the operations. The point A shows an example in which a company is operating at its limit, however, prioritizing the use of resources. Operating on this point, companies have 100% resource efficiency. On the other hand, the point B represents organizations that focus more on flow efficiency and do not prioritize the utilization of resources.

The chart below (Figure 12) shows that the increase of variations pushes the efficient frontier line inwards, making the system less efficient. This can better explain why

the manufacturing industry presents better production rates in comparison to the construction industry (mentioned in the first section of this literature review). The mass production concept can be applied in manufacturing, where primarily companies produce a large volume of similar products. This type of system is more predictable and has less variability. On the other hand, in the construction industry, each project is temporary and unique. Thus, it is necessary to design a specific production system to perform each project. Furthermore, in the construction industry, tasks are performed by people, whom have high levels of variability. Workers do not work at the same pace every day. The standardization of human activities is not as possible to achieve at the same level as machines in the manufacturing industry. Moreover, weather conditions are a relevant variability factor encountered in the construction industry, which is not seen in manufacturing.

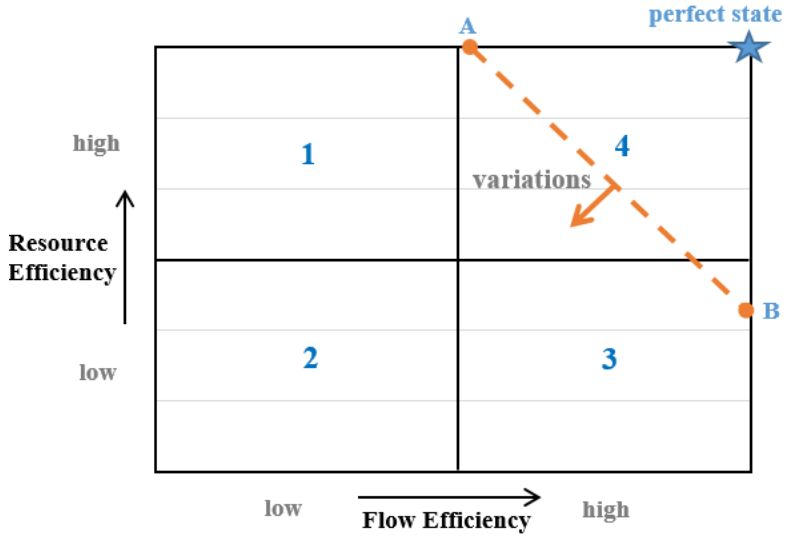


Figure 12: Influence of variations in the two forms of efficiencies (adapted from Modig & Åhlström, 2016)

Companies that can reduce variability in their production system will be closer to the perfect state (star point in the Figure 12). The key point to reduce the variability is to predict the customer demand and have a flexible and reliable supply system (Modig & Åhlström, 2016). In sum, reliability and predictability are the two most important factors that lead companies to achieve the optimum level of their production by reducing variabilities.

LITERATURE REVIEW CONCLUSIONS

The literature review indicated that management issues are the principal agent for failures on construction projects, such as delays and cost overruns. The lack of understanding of the theory of production management and its application, the lack of commitment of project participants, and the use of improper management tools are the basically the main factors that lead to such flaws. Therefore, there is a dire necessity of a construction management technique which embraces the solid theories of production systems and at the same time should be intuitive and understandable for all levels of project participants.

Workflow is a relatively new concept adopted by the construction industry, which has been proved to be an essential element for project success. Four distinct authors cited in the literature review demonstrate the importance of flow in production system in different ways, however, they are strongly related. Firstly, in 1989, Shingo from manufacturing industry defines production systems with two types of flow, process flow and operations flow. An analogy to construction projects, process flow is handoff areas from trade to trade, and operations flow is the movement of trades contractors through different locations of the project. In 2000, Koskela in his dissertation coined the TFV

theory, in which he explains that three elements can comprise construction projects: Transformation, flow and value-added, where transformation corresponds to operations flow and flow to process flow. In 2016, Modig & Åhlström (2016) describe efficiencies in production systems also using two axes: the resource efficiency and flow efficiency. An analogy with Shingo´s view and Koskela theory is also verified, where flow efficiency is correspond to process flow and resource efficiency to operations flow. In 2016 Sacks extended this two-dimensional axes view from these authors to three dimensions for construction projects, creating the Portfolio flow. He assumes that the flow of trade contractors through different projects is the third type of flow.

Chapter 3: The Clear Flow Matrix

INTRODUCTION

Lott Brothers Construction Company (LBCC) founded in 1988 by Wayne Lott and David Lott is a commercial building construction and construction management company. LBCC has constructed some 6 million square feet of completed work in Texas and nearby states. Healthcare construction accounts for about two-thirds of this amount of completed work, or some 4 million square feet. Because many of these projects were located some distance from their home office in Austin, the company was faced with managing the construction schedule and attendant production remotely from the home office. To find experienced site supervisors in those distant areas who are capable of managing the projects mentioned above was an obstacle in itself for the company. Furthermore, during the late 1980s and early 1990s, some of the technological tools that benefit communication and the flow of documents, such as the internet, cloud based scheduling, laptops and cell phones, were not readily available in that period, further complicating the efforts to receive support from construction managers in the home office. A straight-forward and visual tool for depicting production control supporting the project schedule was needed for the site supervisors in those remote projects. Considering the critical need for such a production control technique, LBCC developed the Clear Flow Matrix (CFMx). Initially, the main idea of this technique was to provide a visual and readily understandable aid to the local superintendent to help manage the trades and control the production of work required for the project while making sure the project was in compliance with the Critical Path Method (CPM) master schedule established for the project. In these earliest applications or iterations of this technique applied to renovations to critical care units of hospitals, the Clear Flow Matrix only provided the location (of rooms) and date that each trade crew was

supposed to work in the rooms on a day-to-day basis. Due to the success of obtaining good project outcomes using this new tool, LBCC then proceeded to apply the Clear Flow Matrix to all of its other projects, including large renovation and new ground-up projects. Application to larger projects required certain adjustments including the addition of a weekly tracking period to better accommodate the work flow of larger projects.

The development and the application of the Clear Flow Matrix was primarily focused on the interior finishes of hospital and commercial projects, where the coordination of the location of different subcontractors and trades in the schedule is extremely crucial and must be controlled at the very least on a weekly basis. Industry data shows that these types of projects are often confronted with cost and quality problems due to the acceleration of progress in interior finishes required as the final project completion date approaches. The crews in charge of finishing attempt to complete their work in multiple areas of the project in the last few weeks available for work in order to comply with the master schedule to finish on time, leading to trade stacking wherein multiple trades work in the same area simultaneously. The resulting high density of workers in a confined and congested space negatively or adversely affects the productivity of the trades involved. Based on this theory, the Clear Flow Matrix helps to avoid this unwanted situation. One of the primary abilities of this technique is to locate each crew activity every day on a daily basis constituting an effective production control process.

HOW THE CLEAR FLOW MATRIX WORKS

The clear flow matrix production control method provides a clear visual and intuitive mechanism for managing and controlling the production of building works. This mechanism uses a simple two-dimensional matrix of work locations and trade work items

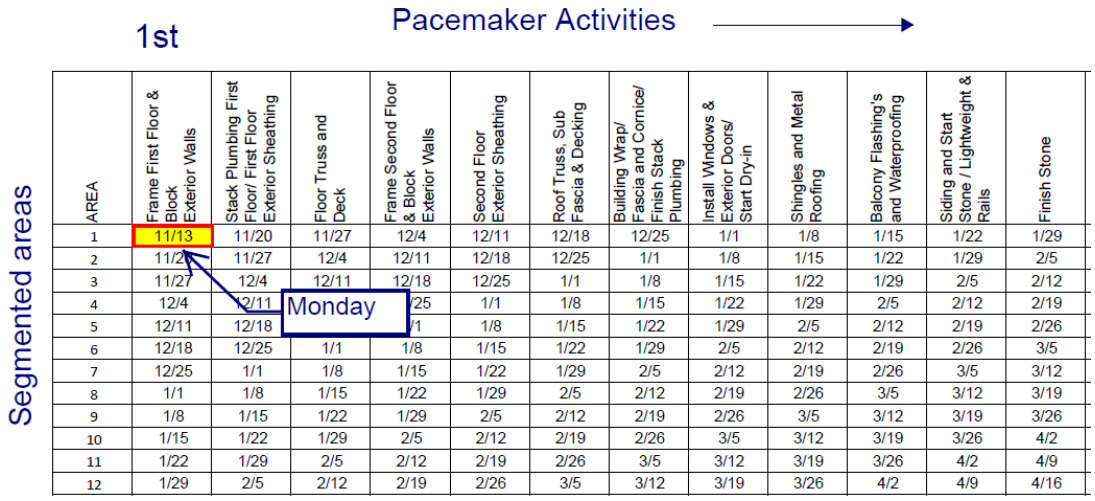
with an embedded third dimension of start date for each trade/location item. Two matrixes can represent the complete construction schedule of the entire project. The Vertical Matrix, which addresses activities with vertical flow of work such as construction of foundation elements and the concrete slab, concrete and steel structure, wall enclosure framing, roof trusses and roofing among others. The second matrix is called Interior Finishes Matrix, which represents activities inside the building with horizontal flow of work (horizontal within a single floor and horizontal within successive floors for multi-story buildings), such as drywall installation, MEP, painting, floor covering and doors among other finish activities.

The first step in composing the CFMx is the identification of appropriate finish areas by carefully splitting the entire project into smaller areas. These areas are listed in the first column of the CFMx. The work items to be performed are identified in the first row labels and are referred to as pacemaker activities, which represent all the trades required for completing the project. The order of the Pacemaker Activities placed in the matrix correspond with the correct logical sequence of activities necessary to build the segmented areas. Thus, all areas will follow the same sequence of work typically encountered in the installation of building finishes. The functional cells in the CFMx indicate the anticipated or scheduled start date of each of the indicated pacemaker activities for the area location segment. The work of each trade within the each of the location areas is to be completed in a period of one week with the starting date always on Monday as shown in the CFMx. The “diagonal line” formed by connecting cells with the same Monday date indicates a date line that represents planned work for the indicated week. During the construction progress of the project, this date line is referred to as the “Balanced Work Front” which depicts the scheduled work status at the indicated date for the various

area locations. As time and the project work advance, the Balanced Workfront moves forward with time and represents the work planned/completed for the status date in each CFMx cell. Any scheduled work that is incomplete and is behind the Balanced Workfront status date is considered, by definition, to be late. All work activities that are underway but incomplete during the indicated week are marked with yellow and the activities already finished are marked in green. Late activities behind the Balanced Workfront are left in blank. In this way, clear and simple identifcation of late (behind schedule) work activities by location area and the number of weeks that such activities are behind schedule are clearly evident by visual review of the CFMx and the Balanced Work Front. Thus, the schedule update and progress review for each scheduled pacemaker work activity is binary; that is, scheduled work in the indicated location area for the week is either complete or incomplete and therefore on schedule or late.

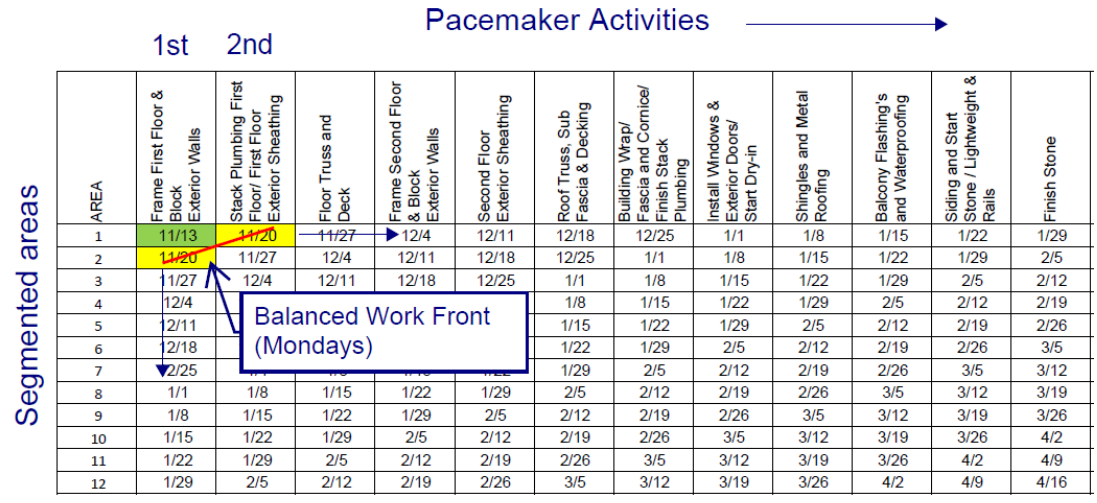
Updating the status of the matrix is accomplished by marking each cell of the matrix with colors according to the scheduled status of the cell in relation to the status date and the Balanced Work Front. The figures 13, 14 and 15 below show this schedule status and update dynamic of the matrix for the first three weeks of an example project in which the project started on Monday, November 13th. In the example, the first activity to be started on the project start date is “Frame First Floor and Block Exterior Walls.” Therefore, only the first cell must be marked with yellow indicating current progress has commenced. For the next week, Monday, November 20th, the work represented by the first activity moves to the next area in the scheduled location area sequence, and the next pacemaker activity in the trade work sequence, which is “stack pumbling first floor and exterior sheathing,” is initiated in the first location area just completed by the first trade in the trade sequence. The finished area from the previous week must be colored with green. In the third week

of the project, the third pacemaker activity, “Floor Trusses and Deck,” is started on the project and the precedent activities move forward to the next areas. This flow of Pacemaker Activities through the location areas continues until the completion date of the project.



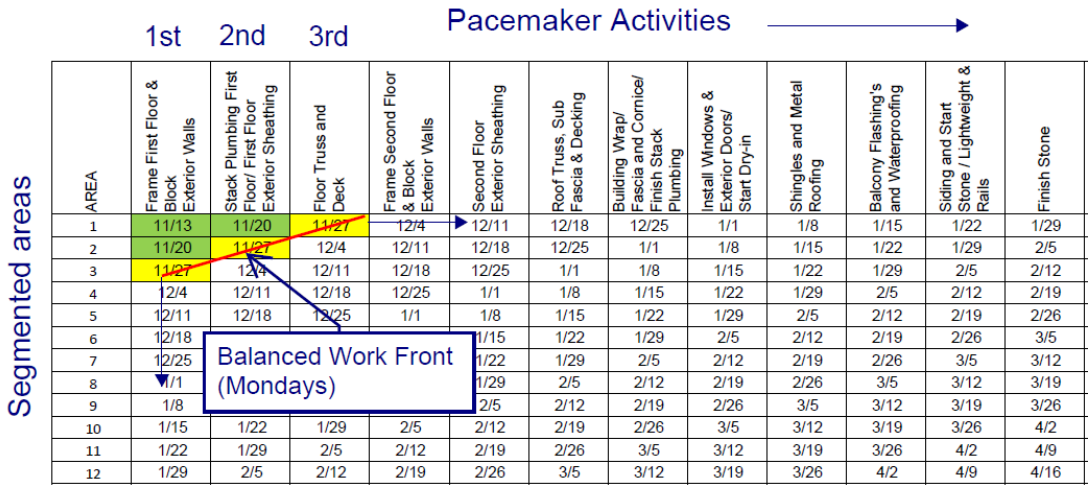
AREA	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone
1	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29
2	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5
3	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12
4	12/4	12/11	[illegible]/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19
5	12/11	12/18	[illegible]/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26
6	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
7	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
9	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
10	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
11	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
12	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16

Figure 13: Representation of the Clear Flow Matrix in the first week of the project.



AREA	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone
1	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29
2	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5
3	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12
4	12/4	[illegible]	[illegible]	[illegible]	[illegible]	1/8	1/15	1/22	1/29	2/5	2/12	2/19
5	12/11	[illegible]	[illegible]	[illegible]	[illegible]	1/15	1/22	1/29	2/5	2/12	2/19	2/26
6	12/18	[illegible]	[illegible]	[illegible]	[illegible]	1/22	1/29	2/5	2/12	2/19	2/26	3/5
7	12/25	[illegible]	[illegible]	[illegible]	[illegible]	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
9	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
10	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
11	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
12	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16

Figure 14: Representation of the Clear Flow Matrix in the second week of the project.



AREA	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone
1	11/13	11/20	~~11/27~~	~~12/4~~	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29
2	11/20	~~11/27~~	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5
3	~~11/27~~	~~12/4~~	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12
4	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19
5	12/11	12/18	~~12/25~~	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26
6	12/18				1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
7	12/25				1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8	1/1				1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
9	1/8				2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
10	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
11	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
12	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16

Figure 15: Representation of the Clear Flow Matrix in the third week of the project.

The figures 16 and 17 below represent the use of the Clear Flow Matrix of a healthcare project, which was constructed by LBCC beginning in 2008. Figure 16 shows the division of the entire floorplan of the project into distinct location areas of work for utilization in scheduling and production control using the CFMx. These location areas and appropriate pacemaker finish activities were then used to develop the CFMx for the project indicated in Figure 17. The location areas are recorded in the first column of the matrix and the start dates of the pacemaker activities are recorded in the appropriate row for the scheduled location area. This example represents the status of a healthcare project as of November 3, 2008 (Monday). As mentioned before, the date in each cell of the matrix is labelled with the start date (Monday) for the indicated work in the respective location area and that the work indicated should be completed by the end of that week. Statusing construction progress is straightforward and is determined by examining the amount of work that is complete, incomplete or late by comparing completion status with the Balanced Workfront (the scheduled or actual timeline). Bottlenecks and anticipated delay

information may be obtained by counting cells of incomplete and late work that lag behind the scheduled Balanced Work Front. For instance, assuming the project of Figure 16 and 17, the activity “Tape/Float Prime” is four weeks behind schedule, and the “Kitchen” is three weeks delayed. In a similar fashion, is also possible to recognize activity acceleration, or work that is being performed ahead of schedule. In the project example in figures 16 and 17 the activity “MEP above ceiling” is two weeks ahead of the Balanced Work Front. As mentioned previously, the representation of CPM schedule usually requires the use of a truckload of documents, culminating in the eventual confusion with regards to the understanding of the schedule of the project as a whole. On the other hand, through the use of the CFMx, the overall construction plan that complements the project CPM schedule can be precisely represented in just a single page.

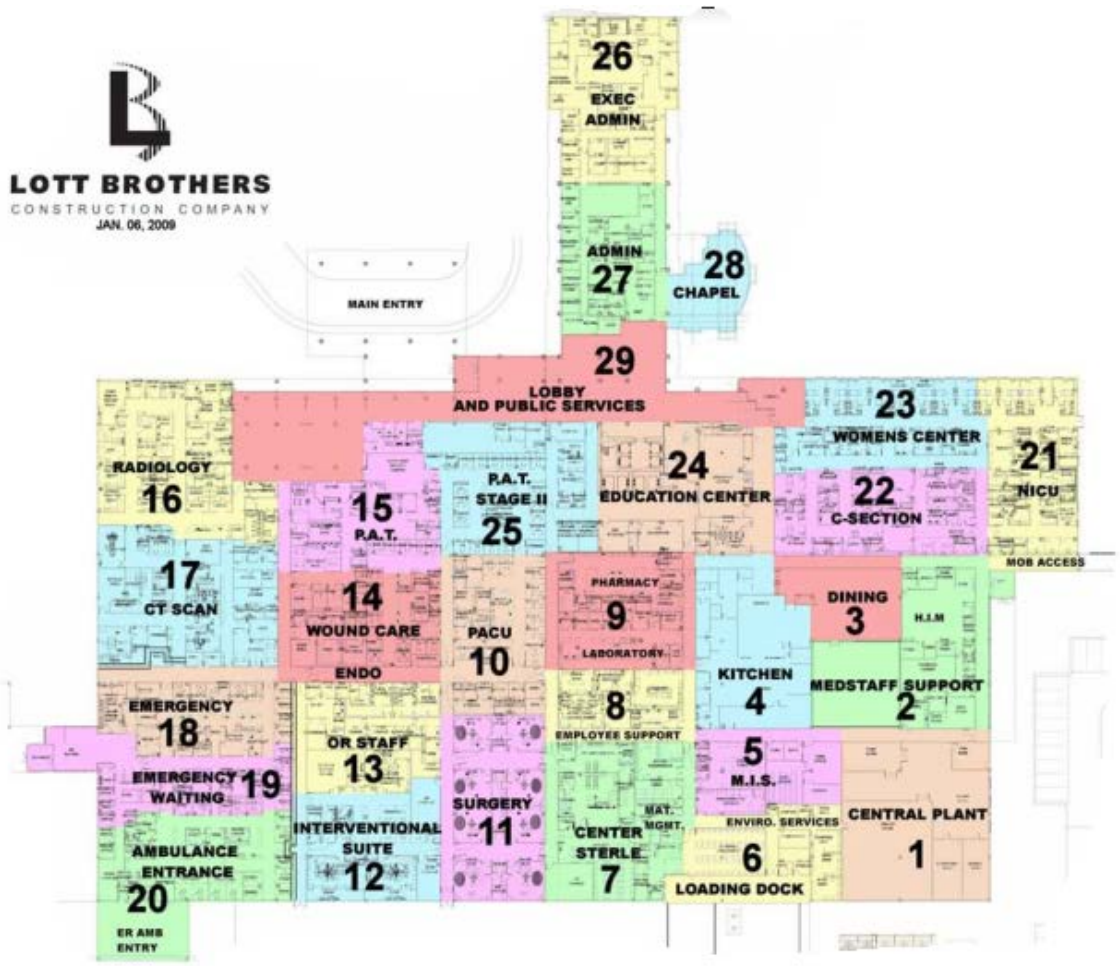
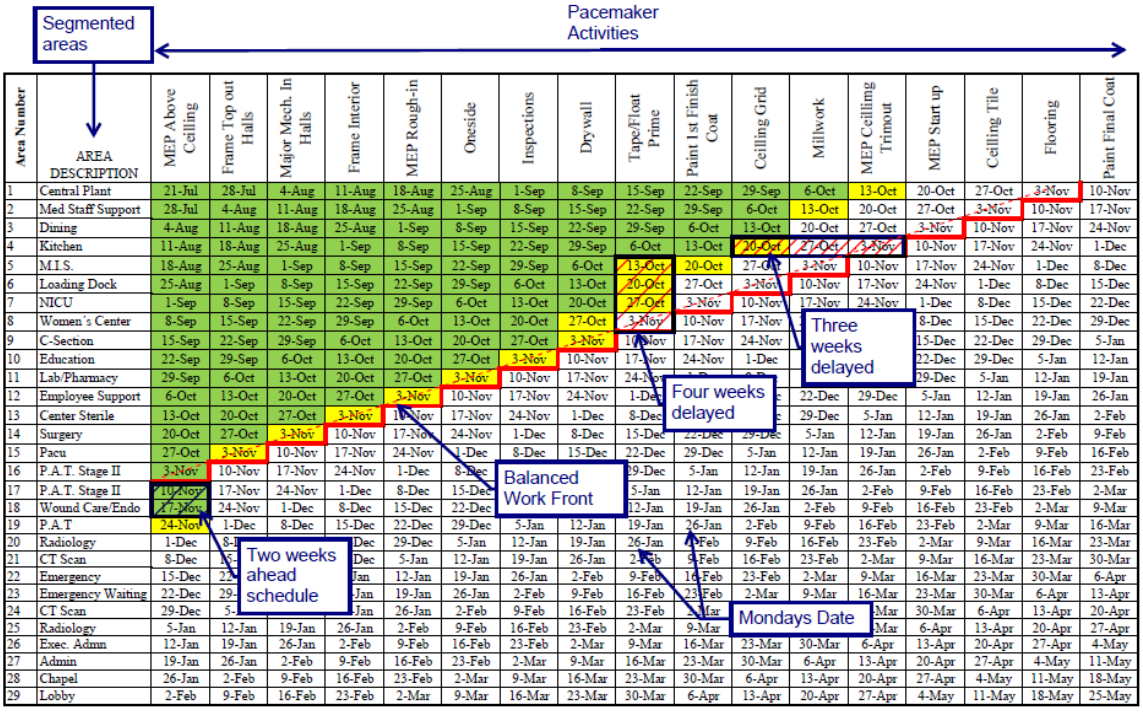


Figure 16 : Segmented areas for the Clear Flow Matrix of a healthcare project in Texas (Source: Lott Brothers Construction Company)



Area Number	AREA DESCRIPTION	MEP Above Ceiling	Frame Top out Halls	Major Mech. In Halls	Frame Interior	MEP Rough-in	Oneside	Inspections	Drywall	Tape/Float Prime	Paint 1st Finish Coat	Ceiling Grid	Millwork	MEP Ceilimg Trimout	MEP Start up	Ceilling Tile	Flooring	Paint Final Coat
1	Central Plant	21-Jul	28-Jul	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov
2	Med Staff Support	28-Jul	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov
3	Dining	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov
4	Kitchen	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec
5	M.I.S.	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec
6	Loading Dock	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec
7	NICU	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec
8	Women´s Center	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov			15-Dec	22-Dec	29-Dec
9	C-Section	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov				22-Dec	29-Dec	5-Jan
10	Education	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec				29-Dec	5-Jan	12-Jan
11	Lab/Pharmacy	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov						5-Jan	12-Jan	19-Jan
12	Employee Support	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec			22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan
13	Center Sterile	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec			29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb
14	Surgery	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec			5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb
15	Pacu	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb
16	P.A.T. Stage II	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec		29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb
17	P.A.T. Stage II	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec			5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar
18	Wound Care/Endo	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec			12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar
19	P.A.T	24-Nov	1-Dec	8-Dec	15-Dec	22-Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar
20	Radiology	1-Dec	8-D		Dec	29-Dec	5-Jan	12-Jan	19-Jan	26-Jan	Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar
21	CT Scan	8-Dec	15-		Dec	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar
22	Emergency	15-Dec	22-		Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr
23	Emergency Waiting	22-Dec	29-		Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr
24	CT Scan	29-Dec	5-		Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	Mar			Mar	30-Mar	6-Apr	13-Apr	20-Apr
25	Radiology	5-Jan	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar			Mar	6-Apr	13-Apr	20-Apr	27-Apr
26	Exec. Admn	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May
27	Admin	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May
28	Chapel	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May
29	Lobby	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May	25-May

Figure 17: The Clear Flow Matrix of a healthcare project in Texas (Source: Lott Brothers Construction Company)

THE CLEAR FLOW MATRIX AND LEAN CONSTRUCTION

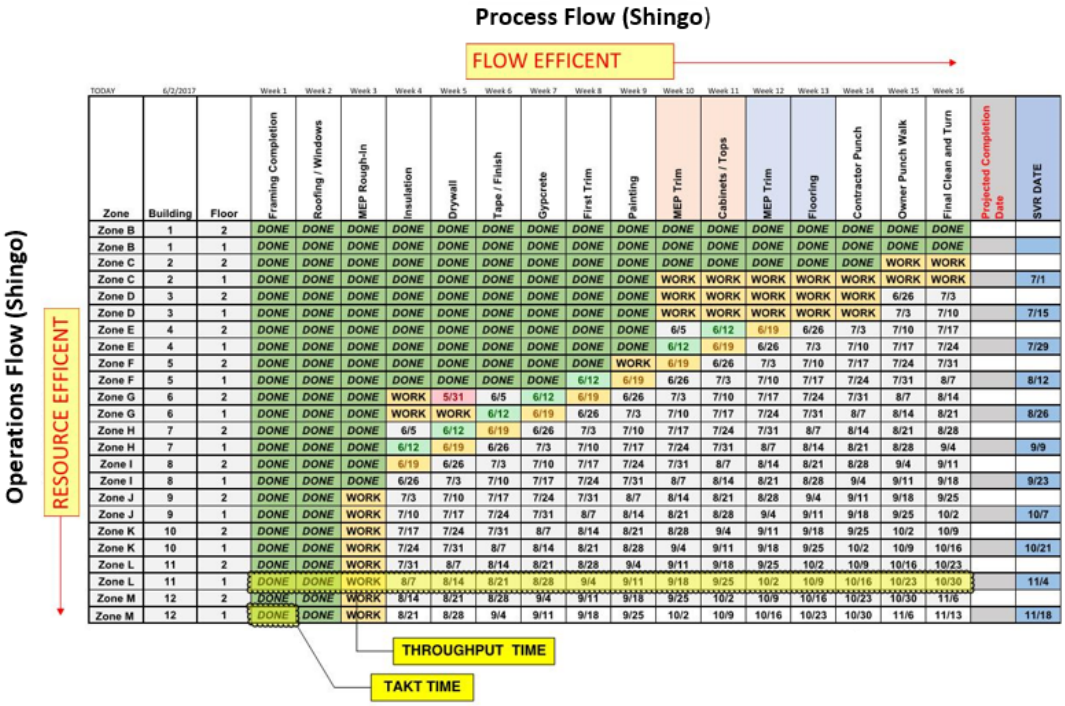
Lott Brothers Construction Company created the first Clear Flow Matrix in 1995. With the growing and on-going implementation of lean thinking and Toyota production concepts from the manufacturing industry into the construction industry, it became evident that the Clear Flow Matrix incorporates certain production control techniques that accomplish many of the tenets of Lean construction and Toyota production. Thus, LBCC transformed some of the Clear Flow Matrix language to better align with their client's Lean Construction terminology to utilize the technique on Lean Construction projects undertaken by the company. LBCC has continued to refine the processes involved in application of the CFMx to construction and determined that use of the CFMx is consistent with basic Lean philosophies of balancing the flow of work on the entire project and not

on just improving production efficiency of a single trade at the possible expense of other trades. To be consistent with the overall purpose of the tool, LBCC titled the production control plan as the clear flow matrix to bring attention to the ways in which the technique clearly identifies the flow of the work and the relationships of flow.

In Lean construction/Toyota production terminology, the fundamental purpose of any concept that aids in the control of production, such as a production flow matrix, is the provision of a method, tool or technique which consistently balances resource efficiency and flow efficiency by effectively communicating the scheduled status of all flow units under production at each takt time interval. The status of each flow unit is easily discernable on a manufacturing line; but flow unit status is less obvious in service-type industries and even more difficult to determine adequately on large building construction projects. Because available tools for that purpose commonly used on work scheduled with activity based CPM management software programs employ some form of earned value calculation for each trade and thus the entire project is a summation of the status of the various trades.

The Matrix below (figure 18) is an example that shows the terminology of Lean Construction, introducing terms such as; Flow Efficiency, Resource Efficiency, Throughput Time and Takt Time. In construction projects, flow efficiency is associated with the process efficiency of the handoff of production in one location area to the next trade in the sequence of work and resource efficiency is related to the operational efficiency of each trade as the trade moves through the sequence of location areas. The balance between resource efficiency and flow efficiency is necessary to have the production running at its most efficient (Modig & Åhlström, 2016). This balance can be achieved through the “Balance Work Front” in the matrix. Looking at the Clear Flow Matrix shown

below, it is also evident to visualize the priorities from Owner´s and Subcontractor´s perspective regarding flow efficiency and resource efficiency. The owner's desire to have a completed project is best served by assuring high flow efficiency with focus on the throughput time thereby assuring a faster completion date of the project. On the other hand, trade contractors focus on high resource efficiency. As discussed previously in the literature review, trade contractors tend to finish their work rapidly to reduce their labor cost and to move available crews to other contracts. With the reference of the Clear Flow Matrix presented below, a production plan which focuses on flow efficiency alone might produce a completed section of the building very effectively only if all the needed resources were available in that area. In other words, conducting the work of the trades in a purely flow-efficient manner or resource-efficient manner does not effectively produce the completed product for the client. Producing completed areas in the building (units or location areas) without other completed areas wastes time, just as completing the entire work of each trade in turn also wastes time. Indeed, it is not possible to complete buidling finishes unless the trade sequence required for the work is respected. The client cannot accept the building until the entire building is completed. The objective is then to develop and follow a production plan framework that balances flow efficiency and resource efficiency so that the client and construction team members are served in a balanced way.



TODAY	6/2/2017		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16		
Zone	Building	Floor	Framing Completion	Roofing / Windows	MEP Rough-in	Insulation	Drywall	Tape / Finish	Gypcrete	First Trim	Painting	MEP Trim	Cabinets / Tops	MEP Trim	Flooring	Contractor Punch	Owner Punch Walk	Final Clean and Turn	Projected Completion Date	SVR DATE
Zone B	1	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE		
Zone B	1	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE		
Zone C	2	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK		
Zone C	2	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK	WORK	WORK	WORK	WORK	WORK		7/1
Zone D	3	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK	WORK	WORK	WORK	6/26	7/3		
Zone D	3	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	WORK	WORK	WORK	WORK	7/3	7/10		7/15
Zone E	4	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	6/5	6/12	6/19	6/26	7/3	7/10	7/17		
Zone E	4	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	6/12	6/19	6/26	7/3	7/10	7/17	7/24		7/29
Zone F	5	2	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	WORK	6/19	6/26	7/3	7/10	7/17	7/24	7/31		
Zone F	5	1	DONE	DONE	DONE	DONE	DONE	DONE	DONE	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7		8/12
Zone G	6	2	DONE	DONE	DONE	WORK	5/31	6/5	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14		
Zone G	6	1	DONE	DONE	DONE	WORK	WORK	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21		8/26
Zone H	7	2	DONE	DONE	DONE	6/5	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28		
Zone H	7	1	DONE	DONE	DONE	6/12	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4		9/9
Zone I	8	2	DONE	DONE	DONE	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11		
Zone I	8	1	DONE	DONE	DONE	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18		9/23
Zone J	9	2	DONE	DONE	WORK	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25		
Zone J	9	1	DONE	DONE	WORK	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2		10/7
Zone K	10	2	DONE	DONE	WORK	7/17	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9		
Zone K	10	1	DONE	DONE	WORK	7/24	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16		10/21
Zone L	11	2	DONE	DONE	WORK	7/31	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23		
Zone L	11	1	DONE	DONE	WORK	8/7	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30		11/4
Zone M	12	2	DONE	DONE	WORK	8/14	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30	11/6		
Zone M	12	1	DONE	DONE	WORK	8/21	8/28	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/23	10/30	11/6	11/13		11/18

Figure 18: Clear Flow Matrix with Lean terminology

In the earlier stages of the project, the same crews begin to move from area to area shown vertically on the matrix and highlighted as “resource efficient” with little disruption since they are not dependent on other trades to complete their work. As the initial crews complete an area (unit) and move to the next/unit, they prepare to hand off the area/unit to the next crews. Here is where the reality of flow efficiency vs. resource efficiency comes to light. The handoff must be managed correctly for the flow of the complete unit (shown horizontally) to progress at the same efficiency as in the earlier stages. This handoff is a perfect place to apply last planner techniques and the planned percent complete is well defined measurable against both flow and resource efficiency.

The clear flow matrix shown above reflects the status of a project comprised of 12 wood-framed 2-story apartment buildings located in Waco, Texas. This project was

several months behind schedule, and the progress on the project was not sufficient to regain the original schedule completion date; thus, the project was effectively out of control. For this reason, the owner of the project contracted with LBCC to provide consultation regarding the project progress and schedule completion status. The original technique used for scheduling and production control on the project was a CPM network based Gantt Bar-Chart depicting detailed schedule activities for each of the buildings. The resulting schedule was presented in some 38 letter sized pages of Gantt chart schedule information. LBCC staff reviewed in the field the current completion status of each building of the project and input this data into a CFMx production control plan to establish a projected date for the completion of the project. This effort generated only one page of information that represents the completion schedule for interior finishes for the entire project. This example use of the CFMx production plan highlights the ease with which managers may employ the CFMx to identify not only the delays, bottlenecks and the trades responsible for delays but also the trade and location areas required for acceleration to complete the project. The status of work completed on the project indicates clearly the poor results that typically result in projects, which do not focus attention on both flow efficiency and operations efficiency on a frequent, perhaps weekly basis. At the Waco apartment project, the first two trades of the project accelarated their work and partially completed their location activities ahead of schedule and effectively left the project with incomplete work in some locations. However, even with the supposed high operations efficiency of these two trades, the project was still delayed because of bottlenecks that developed later and for re-entrant work required to complete work of the supposed operations efficient trades. This situation highlights the need of having a balance between resource efficiency (trades operation) and flow efficiency (process of trade exchange/handoff).

The amount of work required to recover from the delays is clearly depicted on the Clear Flow Matrix by referencing the “06/19” date cells (Figure 18). These constant date cells form a “diagonal” row across the CFMx and depict not only the planned/actual work for the indicated takt time but also the “Balanced Work Front” of construction progress. The Balanced Workfront helps align the late trade-areas with the planned completion schedule and highlights the location areas in which the affected trades are required to work to bring production into alignment with the proposed completion schedule.

As mentioned above, the Clear Flow Matrix easily pinpoints the bottleneck activity, which is represented by columns (trades) composed of white cells (activity not started yet) or yellow cells (activities in the process). As the sequence of pacesetter activities goes from left to right in the first row of the matrix, if one specific trade is delayed, it holds back the trades that follow. The matrix below shows (figure 19) an example status of a project in which the “Floor Truss and Deck” work is the bottleneck activity. Without the installation of floor trusses and deck, the structural frames to be placed on that floor deck cannot be performed. With this situation, it is evident that bottleneck activities worsen the flow efficiency leading to project delay. On the other hand, trades working in areas beyond the Balanced Workfront are wasting effort and resources by creating work inventory that does not improve scheduled completion of the project.

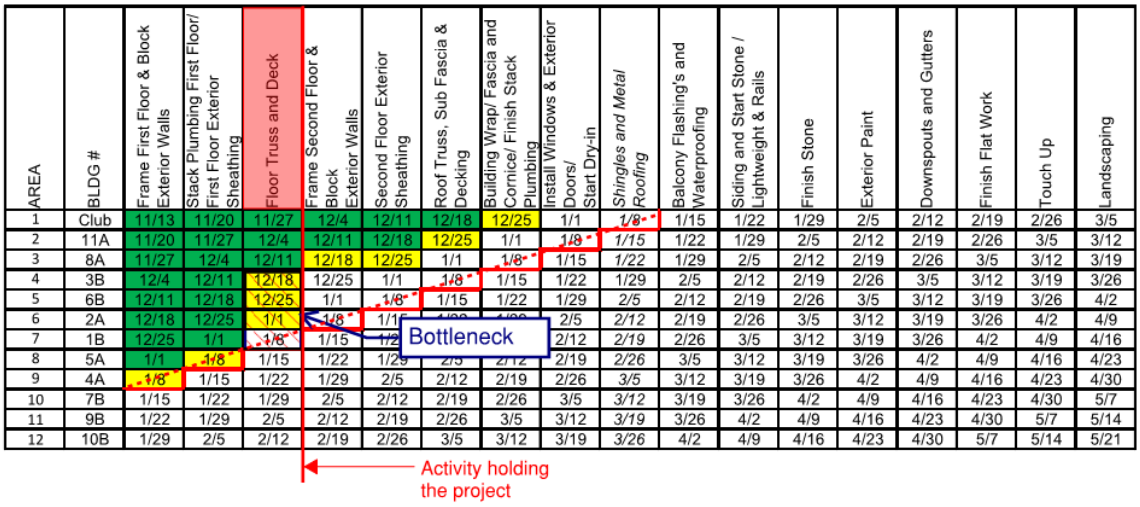


Figure 19: Clear Flow Matrix with bottleneck activity

TAKT TIME AND AREA BREAKDOWN

The weekly basis duration of the Clear Flow Matrix is consistent with the standard planning period routinely used in scheduling and production control on large-scale construction projects. In Lean Construction terminology, this is also the rate of customer acceptance, which is the "Takt Time" for completing and turning over each trade-area as each location area is finished in turn. The use of takt-time planning serves the sustained work flow objective by providing the sequence of trades in defined location areas with the same amount of time (Faloughi et al., 2015). To maintain the one week "Takt Time" for the project, it is necessary during the pre-construction phase to break down the area of the project into smaller pieces, taking into consideration the complexity of each trade. To complete this, some information is required at this stage to determine the most appropriate location area segmentation plans for scheduling the project and preparation of its attendant production control plan reprsented by the Clear Flow Matrix:

- Quantity takeoffs by areas
- Available trade labor information

- Published and in-house crew hour production rates
- Crew composition data
- Supply chain

The goal of any production control system is to deliver the final product that meets client demand. In building construction projects, the final product (building) is composed of several rooms and the customer demand is met when all the rooms are finished, not only part of them. Only by tracking a portion of the total customer needs can the processes be analyzed and improved to achieve a balance between flow efficiency and resource efficiency.

In construction, resources move physically through the rooms (locations) rather than production units move through the workstation as in manufacturing industry. Therefore, it is easy to identify physical portions of a project as units to be completed that will result in the overall completion of the project. This physical portion could be, for instance, walls, slabs, interior finishes and all tied back to the completion of the project through physical constraints and milestone dates established by the customer. Trades should be scheduled to complete portions of the work so that the whole project is not subjected to extreme inefficiencies in completing extensive areas in very reduced times.

These segregated areas have to be correctly sized so that all trades to perform their job in those areas in one week. It allows that the handoffs can be made and tracked on a weekly basis. Faloughi et al. (2015) confirmed what was mentioned earlier that one-week handoff is rational with project control systems. A study conducted by O'Brien (2000) demonstrates that the size of work areas released to subcontractor trades plays an important role on the productivity rate. His research shows that the productivity rate may increase when the available area also increases. However, this relationship continues to a certain

point. After achieving a peak, the productivity tends to decrease with the growth in the area. The chart below (figure 20) shows this relationship between work area and productivity. Demotivation of workers explains this decrease of productivity rate when areas become too large (O'Brien, 2000).

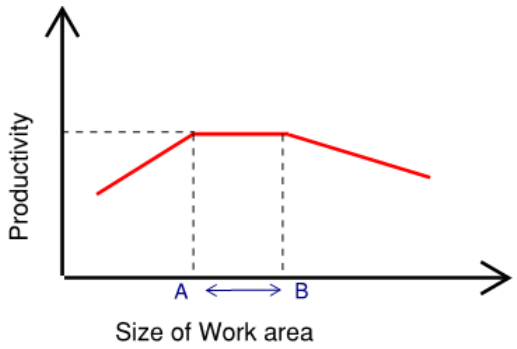


Figure 20: Relationship between the size of work area and productivity (adapted from O'Brien, 2000)

In construction, it is common to have trade contractors requesting large areas to work, so that they can continue the same activity for long as possible. However, the figure above indicates that large areas is not synonymous to being the most productive. Contractors must understand this relationship shown in the chart above (figure 20) correctly size the work areas for subcontractors to achieve a high productivity level and at the same time, meet the as-planned schedule. To set up a scheduling using the CFMx technique it is necessary to combine the takt time of one-week duration and the size of work areas, in which ideally have to be within the two points (A and B) shown in the figure 20 .

PACEMAKER ACTIVITIES

The literature review has shown that production systems must combine both resource efficiency/operations flow and flow efficiency/process flow to achieve good project outcomes. However, productivity has still a high priority and organizations must not neglect it. The Clear Flow Matrix provides a reasonable and competitive pace of production by selecting the pacemaker activities that will include the significant trades on the project. The pacemaker activities are identified in the first row of the matrix and can be one trade or a combination of various trades. The areas should be sized to accommodate the total number of tradesmen. The sum of work of the pacemaker activities result in the completion of the area, and as shown in Figure 18, equal the throughput duration of the area. The throughput duration must be reasonable and often seems a little relaxed when considering one area as a standalone project.

However, as the project progresses, the pressure to maintain flow (completing each area) comes to bear as each trade must prepare to start the next area/unit as well as finish the activities in the current area allowing the next trade to start the following Monday. The trades of each pacemaker activity must complete their work per area in one week, which is represented by one single cell in the matrix. Following this protocol, it avoids out of sequence work. In construction projects, the pacemaker activities are commonly delayed to start closer to the final project completion instead at each area completion. This situation leads to delaying the supply chain activities and inevitably results in the crash programs that have almost become the norm.

CPM and improper pull planning can appear to encourage postponing the “finishes” and later pacemaker for the convenience of site coordination, access, and supply chain decisions. This is so-called convenience is resource efficiency taking priority over flow

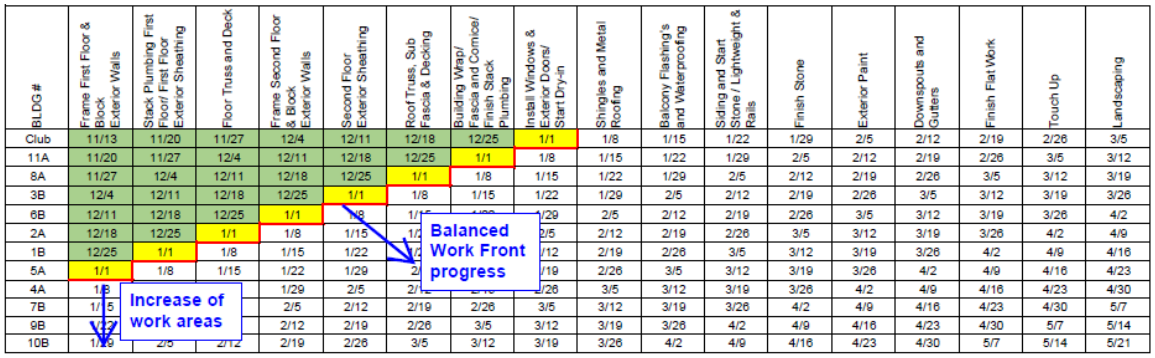
efficiency. This situation results in multiplying change orders and incomplete work throughout the entire project rather than forcing those decisions and resources to complete the customer demand rate per area. Once again, the early inconveniences drive projects to the costly trade stacking, rework, and overtime required to recover from the early decisions. Mockups, BIM, and prefabrication are allowed to be an even greater benefit as areas finish early, and they provide tools to convey information to the following areas.

BALANCED WORK FRONT

As the project progress to completion, new trades start to work on the project while others move into different areas. During the midpoint of the project when the many different trades are on the job site, it is common to have a stacking of trade, which usually becomes a problem for construction productivity, and large inactive areas. The construction industry needs a good management system to avoid this unwelcome situation. Ideally, different trades can be spread in smaller crews and redirected to multiple areas throughout the job site with specific duties. The Balanced Workfront shows this optimal model exactly, demonstrating where and when each trade is supposed to work.

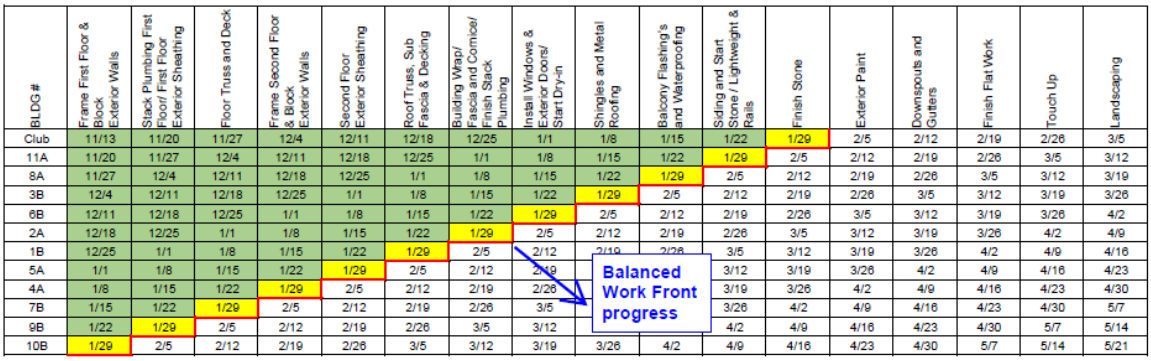
Furthermore, the Balanced Workfront can depict the workload of the project. As the project advances, the number of current work locations (yellow cells) increases from the beginning until a certain time. The workload achieves the peak usually around in the midpoint of the project when all the locations are being worked in. After achieving the peak, either the workload remains the same for a period and starts to decrease or starts immediately to decrease (it depends on the relationship between a number of areas and the number of trades in the matrix). The Balanced Workfront identifies the variation of workload through the project. The figures below illustrate three different situations. The

first (figure 21) shows a status of the project when the numbers of work areas still increase over the time. The second picture shows an example (figure 22) when the project reaches a peak in term of workload, at which point all areas are occupied by trades. The third matrix (figure 23) shows the project status when the amount of work decreases over time.



BLDG #	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone	Exterior Paint	Downspouts and Gutters	Finish Flat Work	Touch Up	Landscaping
Club	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
11A	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8A	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
3B	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
6B	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
2A	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
1B	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16
5A	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23
4A	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30
7B	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7
9B	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14
10B	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14	5/21

Figure 21: Representation of the Balanced Workfront when the project has not still achieved the peak of workload. The work areas increase over the time.



BLDG #	Frame First Floor & Block Exterior Walls	Stack Plumbing First Floor/ First Floor Exterior Sheathing	Floor Truss and Deck	Frame Second Floor & Block Exterior Walls	Second Floor Exterior Sheathing	Roof Truss, Sub Fascia & Decking	Building Wrap/ Fascia and Cornice/ Finish Stack Plumbing	Install Windows & Exterior Doors/ Start Dry-in	Shingles and Metal Roofing	Balcony Flashing's and Waterproofing	Siding and Start Stone / Lightweight & Rails	Finish Stone	Exterior Paint	Downspouts and Gutters	Finish Flat Work	Touch Up	Landscaping
Club	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5
11A	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12
8A	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19
3B	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26
6B	12/11	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2
2A	12/18	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9
1B	12/25	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16
5A	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23
4A	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30
7B	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7
9B	1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14
10B	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14	5/21

Figure 22: Representation of the Balanced Workfront when the project achieved the peak of workload. All areas have trades working.

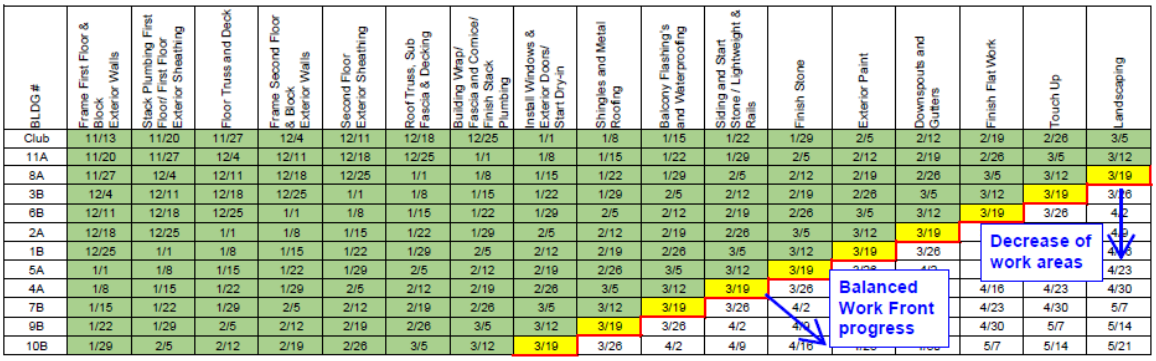


Figure 23: Representation of the Balanced Workfront when the work locations decrease over the time.

Focusing on the start date of a trade location activity rather than end date helps all project participants and managers emphasize the need for supply chain success in lieu of pressuring last planners and installers to accelerate installations to meet promised end dates. Supply chain issues in construction projects are often responsible for completion delays and consequently, trade contractors should be encouraged to complete submittals and other supply chain issues as early as reasonably possible to improve successful on-time starts of their work, which improves on-time completions. The CFMx production control plan provides such emphasis on the need to complete supply chain issues. This focus encourages all work participants to overcome the natural human tendency to wait until the last minute to start preparing for a trade location activity start. The clear and visual nature of the CFMx provides the management clarity required to encourage on-time completion of supply chain issues that are often out of the direct control of the trade supervisors and last planners. This helps supply chain vendors and construction manager support personnel anticipate and schedule the needs for materials, workforce, and space to support trade installations at the construction pace of the Balanced Work Front.

The figure 24 below represents the requirements for a proper flow of the construction project. Many of these requirements are outside of the direct control of the construction manager's site supervisor. Four of the items are prerequisites to start the work activity at the construction site. These are detailing, materials, manpower and space. These items must be planned and scheduled to be available for the trade contractors at the beginning of the activities and not provided sometime during the performance of the work operation. The CFMx through the Balanced Workfront highlights the need for these items before the execution of the activity. The lack of availability of such items as drawings, RFI answers, proper fit details, other trade interference, late material deliveries are often presented as reasons and excuses which delay starting of trade work as trade contractors are requested to initiate work on the site or in a location.

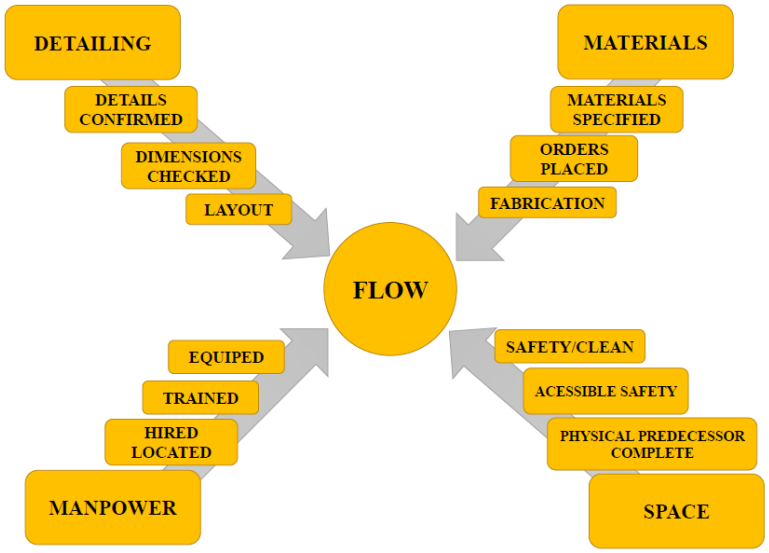


Figure 24: Scheme representing four main elements for achieving proper construction flow.

The literature review shows the importance of balancing flow efficiency and resource efficiency in production management systems. The existing production management techniques applied in the construction industry neither address these two types of efficiencies nor do not clearly represent them. In contrast to existing CPM scheduling management software and production control techniques, the CFMx tracks and balances the tension between flow and resource efficiencies as represented by the Balanced Work Front. As work progresses, the diagonal produced by the same Monday start date becomes the visible scheduled progress and the current status of the project. The CFMx provides a significant planning tool that points out precisely not only which trade contractors and pacemaker activities are behind schedule but also provides specificity regarding the location of the bottleneck and the anticipated delay to the completion date of the project.

The concepts of production stated in Little´s Law indicate that a reduction in throughput time of the project will require a reduction in either work in process (WIP) or an increase in the throughput rate (faster). However, any reduction in WIP to decrease throughput time must not result in a reduction to a WIP amount less than the critical WIP required to deliver the project corresponding to client demand. The Balanced Workfront depicts the critical WIP for the project, that is, the optimal amount of work by trade and location area required per takt period in order to just meet the as-planned master project schedule completion date without any disruption. By working on critical WIP production, the construction manager must ensure that none of the critical WIP trade location area activities undertaken will be starved for any items required for the full planned production of the WIP activities. All the prerequisites to start the work such as resources, information,

laborers and location areas will be available for all WIP-involved trades. Working at the pace of the Balanced Work Front, the project will not exhibit any single bottleneck activity, because all trades will have the same WIP and the same time to handoff their work (five days of takt time). Therefore, all trades are working at the flow pace necessary to just deliver the client throughput and thus are avoiding bottlenecks. If trades are working ahead of the critical WIP, this guarantee of resource availability may not occur, depending upon the trade work under consideration. In construction projects, trade contractors tend to accelerate their schedule so that they can finish their job and move on to other contracts or to accelerate their as-planned payments from later billing periods to earlier ones. However, this often leads to a situation in which areas are not ready for them to start their work, requiring the subject trade to either wait for completion of the preceding trade or to move to some other location within the project to work ahead of another trade. Waiting is a typical example of waste in construction that can be avoided with production management techniques, such as the CFMx. Trades working ahead of the Balanced Workfront are not adding value but are, instead, creating additional WIP that does not increase throughput nor shorten the schedule. This highlights in practice the efficiency paradox and clearly shows that all trades must finish their work in-turn according to the CPM master schedule reflected in the CFMx production control plan at the pace of critical WIP indicated by the Balanced Work Front.

This is an ideal production concept that results in the optimal work flow for the project required to complete the client demand in accordance with the master CPM schedule developed for the project. This does not mean that the proposed or planned schedule is the overall optimal delivery schedule for the project as such an optimal schedule may not be identifiable (Goldratt, 1997). It does however mean that the CFMx will deliver

the customer demand as scheduled by the planned approach without waste caused by bottlenecks or waste caused by excessive WIP.

Sacks et al. (2016) state that a good flow in construction projects exists when the workers can work continuously in different locations at a stable production rate. The figure 25 below presents an ideal project with the optimal workflow. The lines represent the movement of trades through different locations of the project. The continuous lines mean that for this project the ideal workflow is achieved, indicating that there are neither activities requiring re-entrance nor is there any need for workers to wait to perform their work. The parallel lines indicate that the trades are working at the same pace, ensuring the project to have a continuous and smooth handoff process. This ensures that each area has only one trade working, which prevents the stacking of trade situations. On the other hand, the Figure 26 below presents three projects with a discontinuous workflow. The inclination of the lines varies through trades and through the time. It means that the trades are working in different rhythms. This unwelcome situation leads the trades to have waiting times and to work in the same area with other trades at the same time.

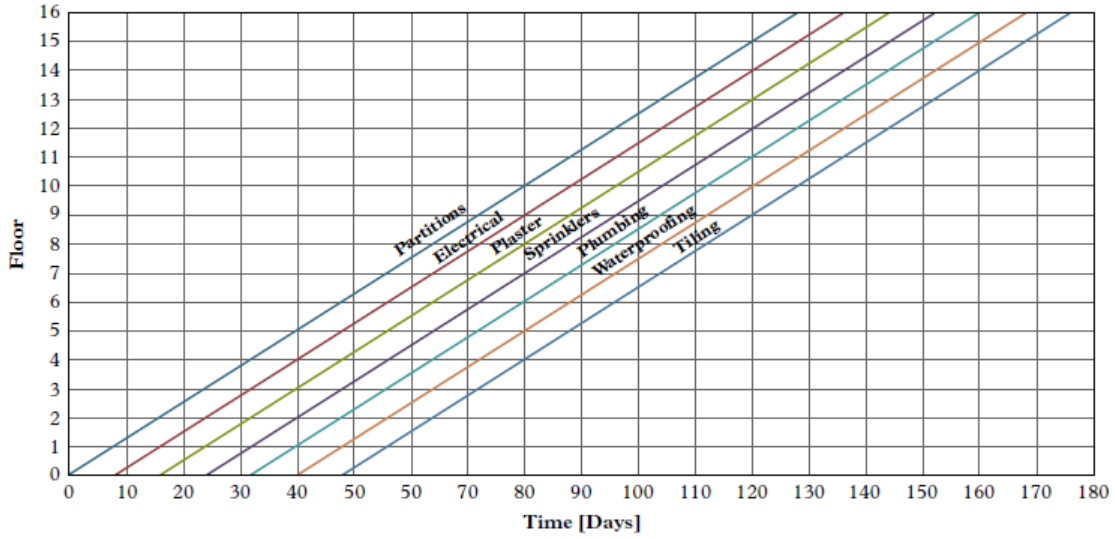


Figure 25: The optimal work flow (Sacks et al., 2017).

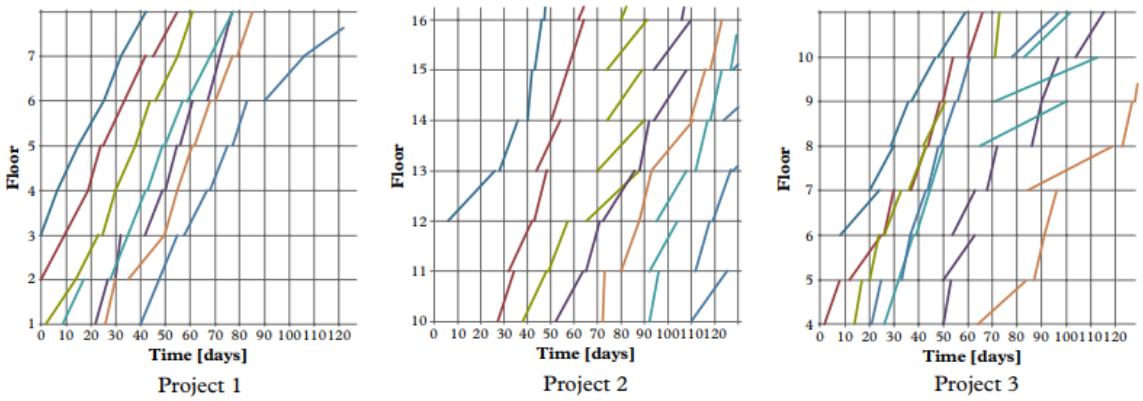


Figure 26: Three projects with discontinuous work flow (Sacks et al., 2017).

The achievement of the optimal workflow in construction projects is a difficult task for the construction delivery team to accomplish due to high uncertainties in the marketplace, weather and project site conditions and constraints. Trade contractors tend to focus on their task without considering how the variability in their capacity affects the project workflow due to the interdependency among different trades. Through management techniques, construction projects can enhance their plan reliability, consequently enhancing the workflow. A reliable workflow makes sure that all resources are available at the right time (Thomas, 2002). The Balanced Workfront is a tool that helps improve production reliability by balancing the two types of flow, operations flow and process flow. The standardization of the pace of work (one week takt time) for all trades provides projects with a structured framework to use to deliver the project team with more predictable and stable flow that meets the client demand. It is worth highlighting that achieving the optimal construction flow is not equivalent with stating that all trades have achieved the maximum productivity; it is, however, the optimal productivity achievable for the trade, given client demand and subject to consideration of other trade contractor work all in accordance with the delivery program of the CPM master schedule. This is because of the variation of

location areas and the content of work through the different locations of the project. However, most work by trade contractors is conducted in a marketplace which can place other-project portfolio demands for labor being utilized on any project of interest. Stable demand and predictable increases or decreases in the trade-labor demand of the project of interest can be managed through effective application of the PPO model (Portfolio, Process and Operations) as suggested and described by Sacks (2016). It is common that some trades do not need one week (takt time) to perform their work in a specific location area. Trades can finish earlier their work and can move to other contracts to avoid idle time on the project of interest with a scheduled return as planned. In application of the CFMx technique, pre-construction planning with the major trade contractors helps reduce between location-area variations of work for the trades.

Sacks et al. (2016) defined optimal conditions that lead to the ideal workflow as mentioned in the chart above (figure 25). Through application of the Balanced Workfront of the CFMx production control framework, the construction managers may obtain the majority of these conditions, which are shown below as adapted from Sacks (2016):

1. Uniform takt time for all trade location areas;
2. Each trade should occupy only one location during the same takt time;
3. Reduce time buffer between trade exchanges;
4. Reduce number of operations to essential minimum required (critical WIP) to prevent waste;
5. Reduce re-entrant workflow;
6. Reduce rework through handoff acceptance;
7. Workflow is made reliable through the make-ready process to remove contraints;

8. The number of locations with work in progress is equal to the number of trade crews, that is, work on critical WIP to reduce WIP buffers;
9. Provide stable within-trade operation production rates to extent practical across locations given client demand schedule;
10. Wasted operation time for each trade is reduced by careful design of handoff/make-ready process.

HANDOFF PROCESS

In today's building construction marketplace, the installation is often performed by trade contractors rather than by direct-hire employees of the construction manager or general contractor. Trade contractors desire to complete as much work as quickly as possible to not only maximize within-project production but also to employ surplused labor on other backlog work in their portfolio of projects. In building work, it is very important for all trades to realize that their work is tied inexorably to the trades that preceed and follow their work in the building, it is the very nature of building construction. Thus, each trade contractor must acknowledge that the project delivery team must work together within a production control plan or framework that delivers a quality product to the client within the time constraints of the construction manager's agreement with the client.

As mentioned in the literature review, flow efficiency is crucial in any type of production system. In construction projects, this efficiency depends on the handoff process between trades. Each trade supervisor must respect and be accountable to the other trade supervisors to create the teamwork atmosphere imperative to a balanced project. As the team begins to develop, the emphasis on accountability to each other grows and is demonstrated daily, as the preparations for location area handoffs become the prime topic

of coordinating day to day activities. **Using the Clear Flow Matrix production control plan, the handoff process transitions or transfers between trades tend to improve over the course of the project. From the beginning to the end of the project, the trades follow the same sequence. This protocol enhances the work atmosphere among different trade contractors**.

Moreover, the Clear Flow Matrix gives each supervisor transparency of which area their trade must complete in the current week and which area their trade should prepare to undertake for their work during the following week. As the Clear Flow Matrix shows precisely the amount of work (areas) per week during the construction, trades have plenty of time to prepare supply chain and other constraints for the pace of the project and establish the ideal crew size. Effective communication among all trades and the construction manager is vital to project success. All project participants must touch base with the schedule status, which must be clear so that everybody can understand. The Clear Flow Matrix provides the information of the project status in one single page. Application of the clear flow matrix to construction projects suggests that the CFMx should be formatted to be printed on 11x17 sheets that also show the location area plan and other important information. The sheets may be laminated for durability prior to distribution to each trade supervisor and trade foreman. In practice, it is common to see the laminated CFMx plans in craft tool boxes. Updating (showing completed work) of the CFMx during the weekly construction meetings assures excellent communication among all trades and this works to highlight supply chain and other constraints as well as limiting any confusion concerning production needed to maintain the contracted construction schedule.

The activities of the site supervisors on Fridays as they complete the work of an area and prepare to move into next area are outlined below. The chart below (figure 27)

emphasizes the routine that can be established to avoid the confusion and uncertainty promoted by vague and verbal instructions. The Balanced Workfront leaves no room for confusion and ample time for planning.

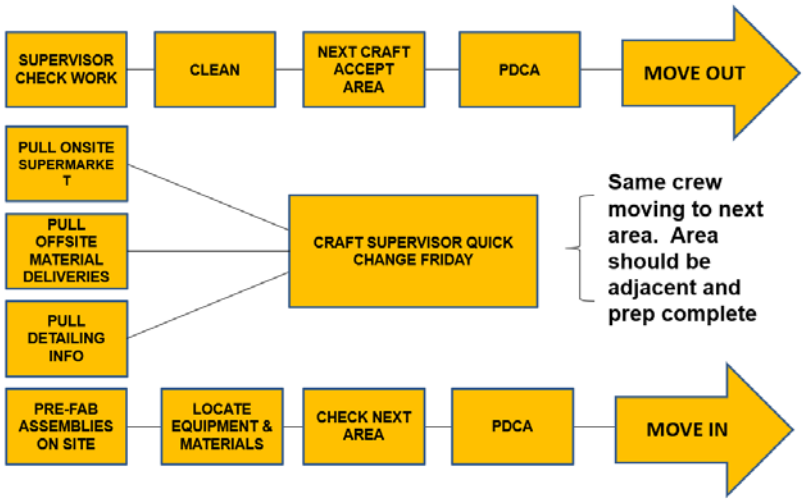


Figure 27: Scheme of handoff process

Chapter 4: Data Gathering and Data Analysis

Data gathering plays an important role in construction projects because the results can pinpoint problems encountered on job sites that preclude high productivity and identify precisely where these issues come from. There is no better way of gathering job site information than asking people who are working on the project and often visit job sites to observe how the work is being performed. For this master thesis, these two approaches were undertaken. However, the outcomes of the data collection have the objective of answering the research questions and not giving suggestions for improvements.

As mentioned in the introduction chapter, this master thesis has the objective of reporting three topics, which are as follows: Assess the effectiveness of the CFMx; Compare the effectiveness of CFMx with other production control techniques; and Compare the Clear Flow Matrix and CPM in a daily management process. To answer these three research questions, the two approaches cited above were used to collect data during the development of this thesis, which are:

1. Work Sampling Analysis in three different projects where the CFMx has been used;
2. Questionnaires/Interviews with foremen and project managers from subcontractor trades.

In the upcoming sections, the outcomes of each one of these techniques will be shown and discussed separately.

WORK SAMPLING ANALYSIS

The central point of this research is to assess the efficiency of the CFMx in construction projects. However, there is no metric or an exact approach that measures the

effectiveness of management techniques for construction projects. The comparison between the job site cost and project estimate has been the most common manner to do so, (Parker & Oglesby, 1972). Nevertheless, this method of comparison sometimes is inadequate mainly when the evaluation must be done during the execution of the project because cost reports may not be completed or accurate, undermining the assessment of outcomes. Furthermore, cost reports usually take time to be compiled and are not immediately available for review by project managers. Therefore, a rapid and easy method that can represent a metric to evaluate the effectiveness of management is needed. According to Parker & Oglesby (1972), a direct way to measure management is to measure resource utilization, which includes equipment, labor, and materials. Because materials are purchased by administrative staffs and their quantity is determined by specifications, and equipment utilization is part of field supervision to manage, labor is the only one of these three elements that managers can manipulate on job sites (Parker & Oglesby, 1972). Therefore, analyzing the efficiency of labor on job sites can be a system to investigate the management effectiveness of construction projects. This is exactly what this thesis strives for: A direct approach that can measure the effectiveness of the CFMx. For that reason, Work Sampling Analysis was chosen to help answer the research questions.

Work Sampling Analysis is a technique that measures the efficiency of time utilization of craftsmen in job sites (Gong et al.,2011). This technique records how the construction workers are spending their time on job sites. It is important to note that the outcome from Work Sampling Analysis is a percentage of time. Thus, it does not directly measure worker's productivity, because no output data are collected (for instance, how many pieces of sheetrock were installed, or how many square feet of tiles were placed). A high percentage of doing activities does not mean high productivity. Workers being busy

does not necessarily translate to them being productive. For instance, a worker with a hand saw can have a high percentage of time working, but another worker with a skill saw can accomplish much more work even though he or she is not work at as high percentage of direct work.

The procedure of collecting Work Sampling data involves walking through different locations on job sites and taking snapshots of workers. To scrutinize the time spent on job site, it is necessary to create categories, in which every observation must be associated with each of the categories. These categories can be determined in different ways. This research classifies the Work Sampling data into three main topics: productive work, supportive work and idle. However, the supportive category is subdivided into three subcategories; which are travel, transport, and instruction, and the idle category is further subdivided into two subcategories, which are personal and idle. The description of each of these subcategories are shown in the table 3 below:

Category	**Subcategory**	**General Description**
Productive	Direct work	Workers doing physical effort directed towards an activity or physically assisting in these activities.
Supportive	Transport	Transporting of tools, equipment or material from one part to another.
	Travel	Walking with empty handed without tools, materials or technical information.
	Instruction	Receiving assignments and determining requirements prior to perform tasks.
Idle	Personal	Personal time taken or idleness taken during normal work hours and normally not attentive to work.
	Idle	Periods of waiting or idleness.

Table 3: Categories of Work Sampling used in this research

The literature review showed some considerations from different authors about production system. First, Shingo represented production with two axes, the process flow and operations flow. Koskela in his dissertation created the TFV theory, in which transformation is associated with operations flow and flow with process flow. In 2016, Modig & Åhlström proposed that production systems consist of two elements, resource efficiency and flow efficiency, that can be related with operations flow and flow process flow respectively. However, flow in construction is hard to grasp and measuring it is even harder, since construction flow units are stationary. Koskela defined that time is the unit of flow in any production system. He also stated that the throughput time is composed for four elements: moving, inspecting, processing and waiting time. This means that resources are spending their time in one of these four elements when they are producing something, in which only processing is value added and the others are considered waste.

If Work Sampling Analysis shows the percentage of time in each category that workers are spending on job sites and time is unit for measuring flow, a strong synergy between Koskela´s view and Work Sampling Analysis can be identified, as demonstrated in the scheme below (figure 28).

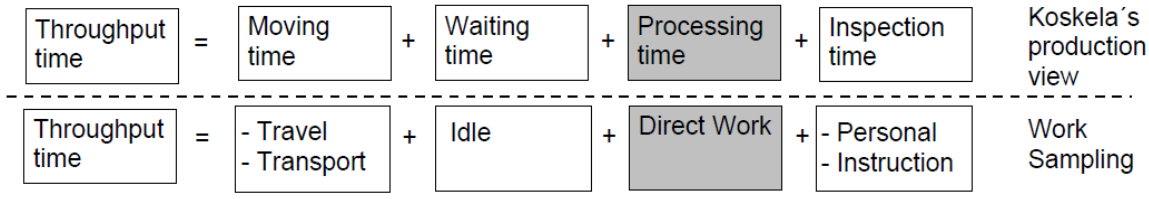


Figure 28: Synergy between Koskela's production view and Work Sampling

The figure above shows that processing time is the only value-added activity that is represented by direct work in Work Sampling. Furthermore, flow efficiency, according

to Modig & Åhlström (2016), is the capacity for generating valuable time during the throughput time. Wernick and Lidelo (2016), represented the flow efficiency with the following formula.

$$Flow\ Efficiency = \frac{\sum Value\ added\ times}{Throughput\ time}$$

If the value-added time is direct work and throughput time is the total time in the process, the Work Sampling outcomes can be a measurement for flow efficiency, as stated in the formulas below.

$$\frac{\sum Value\ added\ times}{Throughput\ time} = \frac{Direct\ Work}{D.Work + Travel + Trans + Instr. + Pers. + Idle}$$

Corresponding to the TFV theory from Koskela, the two types of efficiency as Modig & Åhlström (2016) described, and the Work Sampling Analysis provide an approach to evaluate flow in construction projects. Therefore, Work Sampling Analysis can measure not only the effectiveness of management in construction projects, (Parker & Oglesby, 1972), but also the flow efficiency of the system.

Work Sampling Data Collection

It is unreasonable to observe construction workers every minute every day to collect data for Work Sampling. However, a minimum amount of observations must be performed so that the sample is representative for the work on whole project. It is evident that, the larger the number of observations collected, the closer the outcome to the real situation will be. Oglesby et al. (1989), uses three statistical terms to establish this minimum margin

amount. These are confidence limit, limit of error and category proportion. Confidence limit expresses the uncertainty about the data. In other words, it gives the interval in which the results fairly sure will lie in. Limit of error is the accuracy of the result in percentage variation on either side of the value. Category proportion is the portion of the sample having the characteristic that is being observed. Oglesby et al. (1989) defines a proper indicator for each of these three categories that can be used for Work Sampling Analysis: Confidence level of 95%, limit of error of ±5% and proportion of activity within the range of 40% to 60%. To determine the minimum margin amount, the observer must plot the statistics values on the nomograph as shown the figure 29 below. According to the chart, the minimum amount of observations is 385. This number was considered every time when the Work Sampling was collected in job sites.

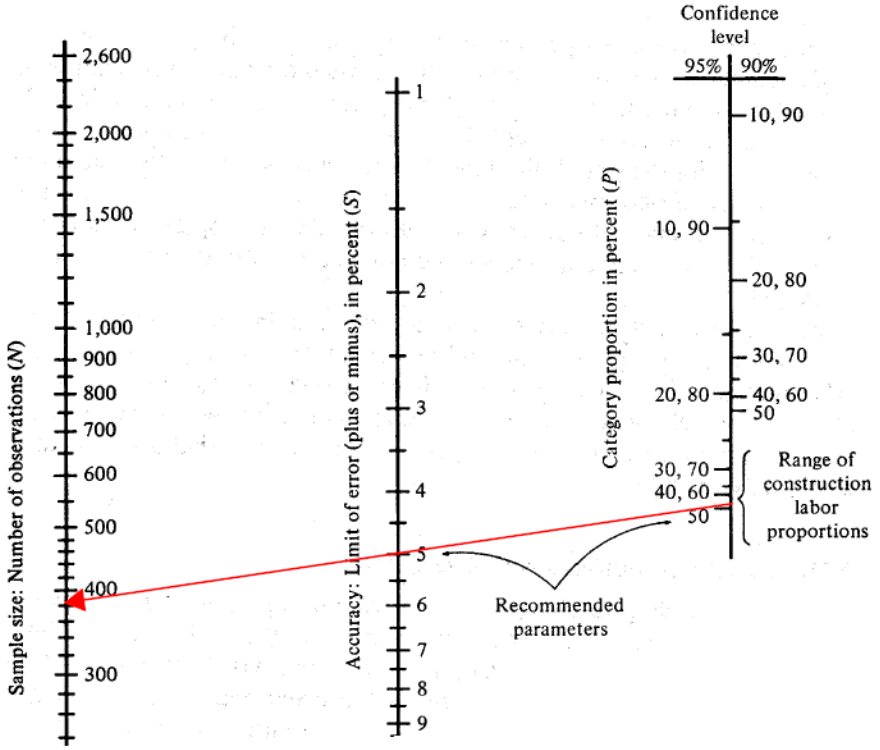


Figure 29: Nomograph for relating sample size

Moreover, Oglesby et al. (1989) defines some general rules for Work Sampling that were also taken into consideration in the thesis. These rules are:

1. At any time, every craftsmen shall have the same chance of being observed
2. Observations must have no sequential relationship
3. The data has to be collected at the instant each man is first seen

During the development of this thesis, Work Sampling Analysis was performed on three different projects where the CFMx has been used. To bolster the validity of the data, these three projects have different types of construction; Project A is a multifamily apartments project, Project B is a school, and Project C is healthcare project. A brief description of each of the projects is shown in the next sections.

Work Sampling Results

This section presents the outcomes of Work Sampling Analysis for each project separately. Afterwards the results will be compared with the industry averages encountered in the literature.

Project A – Multifamily Apartments

This is an apartment development located in Buda, Texas. This project has a total building area of 284,788 square feet. The complex will consist of eleven buildings, housing 256 apartments units ranging in size from studios to three-bedroom units. The complex also includes detached garages, a clubhouse with pool, maintenance building and car care center with dog washing station, dog parks, and pet playground.

The first four job site visits for collecting data were performed by graduate students from the University of Texas at Austin for the class Construction Productivity Improvement. In that period the project was in the initial phase (Site development stage),

and therefore, the activities observed were excavations, pouring concrete for slabs on grade, retaining wall for storm water collection pond, waste water collection system excavation and backfilling. Later in February 2018, the data collection resumed and continued until the first week of April, when the project was in a more advanced stage with many interior finish activities. On construction job sites, it is very common to have turnover of different subcontractor trades as the project advances. Therefore, having data from different stages of the project strengthens the validity of the results, because a wide range of different activities from many subcontractor trades can be analyzed. The table 4 below depicts the data for each day on job site and their respective results.

Project A - Multifamily Apartments - Buda, Texas										
Date	**10/18/2017**	**10/19/2017**	**10/20/2017**	**10/26/2017**	**02/20/2018**	**03/06/2018**	**03/20/2018**	**04/03/2018**	**Total**	**Total (%)**
Time	**1pm-4pm**	**9am-3pm**	**9am-3pm**	**8am-11am**	**8am-12pm**	**8am-12am**	**8am-12am**	**2pm-5pm**		
Direct Work	**307**	**702**	**685**	**711**	**205**	**215**	**201**	**223**	**3249**	**50%**
Transport	67	83	105	86	26	34	37	54	492	7%
Travel	95	124	117	51	68	50	50	46	601	9%
Instruction	54	72	64	47	16	12	25	10	300	5%
Total Suportive	**216**	**279**	**286**	**184**	**110**	**96**	**112**	**110**	**1393**	**21%**
Personal	29	101	80	42	10	18	10	13	303	5%
Idle	150	376	391	324	85	79	71	80	1556	24%
Total Idle	**179**	**477**	**471**	**366**	**95**	**97**	**81**	**93**	**1859**	**29%**
Total	**702**	**1458**	**1442**	**1261**	**410**	**408**	**394**	**426**	**6501**	**100%**

Table 4: Work Sampling outcomes of Project A.

The figure 30 presents the direct work ratio in different dates and phases of the project.

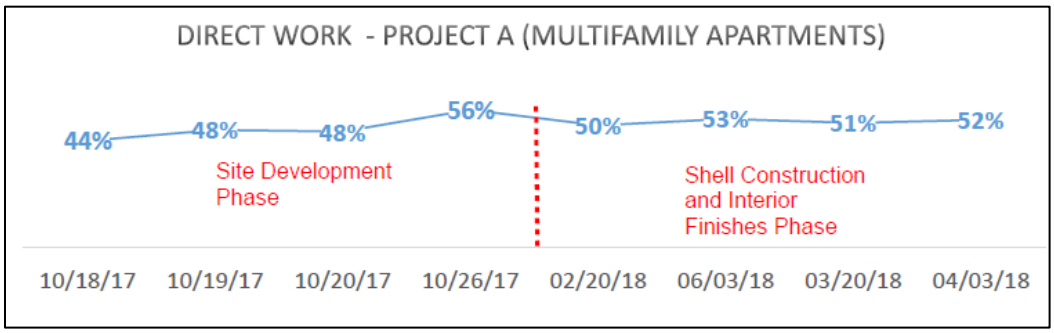


Figure 30: Direct work outcomes of the Project A in two project stages.

The chart of the Figure 31 below shows the outcomes for the Project A considering all categories of the Work Sampling.

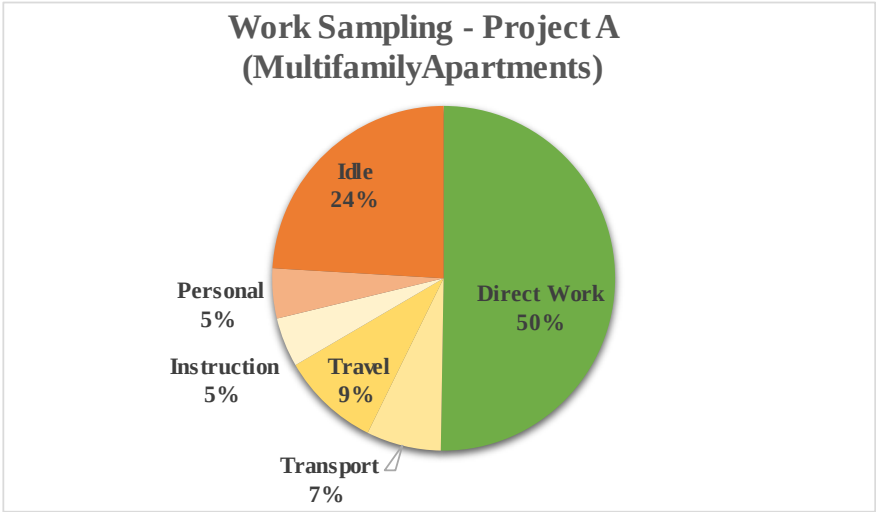


Figure 31: Work Sampling outcomes of the Project A

Project B – School Project

This project is a school building, located in Pflugerville, Texas, and consists of more than 72,000 square feet, a two-story classroom building, administration area, gymnasium, cafeteria, and kitchen. The site will include play areas and ball fields.

The data collection for this project was initiated in October 2017 and was performed by graduate students of the University of Texas at Austin for the course of Construction Productivity Improvement. Again, in that period only excavation, foundation, and slab on grade activities were being performed. In April 2018, the Work Sampling data collection resumed and three more job site visits were performed. In that stage, the project had achieved its peak in terms of workload, with many subcontractor trades working on the interior finishes activities. The table 5 below depicts the data for each day on job site and their respective results.

Project B - School - Pflugerville, Texas							
Dates	**10/18/2017**	**10/25/2017**	**04/17/2018**	**04/23/2018**	**04/30/2018**	**Total**	**Total (%)**
Time	**1pm-3pm**	**1pm-3pm**	**1pm-4pm**	**9am-12am**	**9am-11am**		
Direct Work	**578**	**601**	**190**	**198**	**199**	**1766**	**53%**
Transport	51	40	52	66	46	255	8%
Travel	89	113	45	56	51	354	11%
Instruction	50	71	10	13	11	155	5%
Total Suportive	**190**	**224**	**107**	**135**	**108**	**764**	**24%**
Personal	41	43	13	9	6	112	3%
Idle	199	218	100	78	82	677	20%
Total Idle	**240**	**261**	**113**	**87**	**88**	**789**	**23%**
Total	**1008**	**1086**	**410**	**420**	**395**	**3319**	**100%**

Table 5: Work Sampling outcomes of Project B.

The figure 32 presents the direct work ratio in different dates and phases of the project.

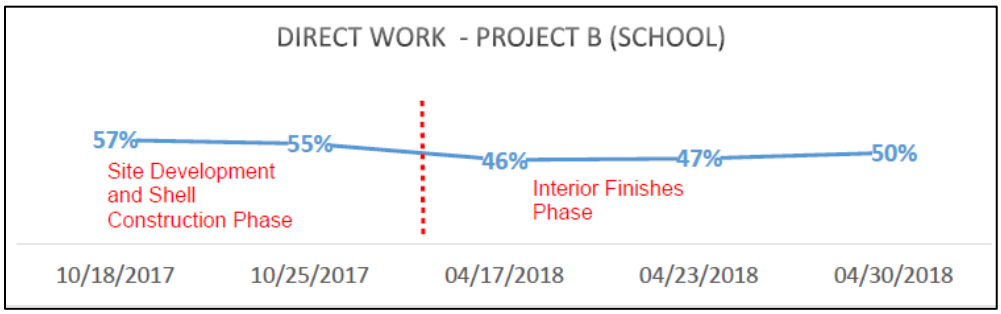


Figure 32: Direct work outcomes of Project B in two project stages

The chart of the Figure 33 below shows the outcomes for the Project B considering all categories of the Work Sampling.

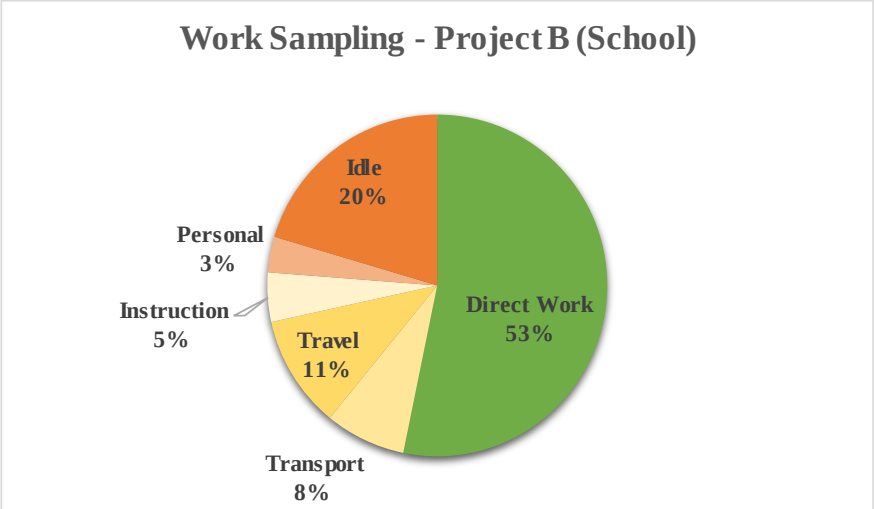


Figure 33: Work Sampling outcomes of Project B

Project C – Hospital

This project consists of the new construction of the 48,000sf, two-story Round Rock Rehabilitation Hospital which will be a 40 patient bed nursing facility comprised of patient rooms, exam rooms, inpatient/outpatient gyms, dining and servery spaces. Trades include, but is not limited to concrete, mansory, metals, millwork, thermal and moisture protection, openings, finishes, specialties, food service equipment, radiation protection,

elevators, mechanical, electrical, plumbing, fire protection, fire alarm, nurse call, earthwork and paving.

The data collection of this project started only in April when the project was already in the interior finishes stage. In total, four job site visits were performed resulting in a substantial amount of data for Work Sampling Analysis. The table 6 below depicts the data for each day on job site and their respective results.

Project C - Hospital - Roundrock, Texas						
Dates	**04/17/2018**	**04/23/2018**	**04/30/2018**	**05/10/2018**	**Total**	**Total (%)**
Time	**9am-11am**	**2pm-5pm**	**1pm-4pm**	**9am-11am**		
Direct Work	**205**	**199**	**205**	**212**	**821**	**50%**
Transport	41	40	41	38	160	10%
Travel	50	55	46	47	198	12%
Instruction	15	25	8	14	62	4%
Total Suportive	**106**	**120**	**95**	**99**	**420**	**26%**
Personal	8	15	7	6	34	2%
Idle	100	80	99	88	383	22%
Total Idle	**108**	**95**	**106**	**94**	**403**	**24%**
Total	**419**	**414**	**406**	**405**	**1644**	**100%**

Table 6: Work Sampling outcomes of Project C

The figure 34 presents the direct work ratio in different dates and phases of the project.

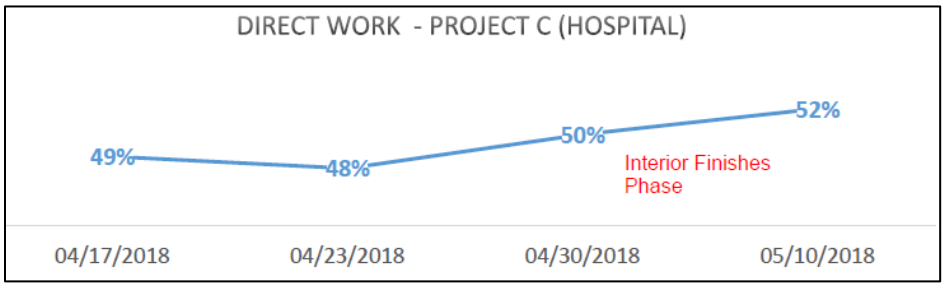


Figure 34: Direct work outcomes in Hospital project in interior finishes stage

The chart of the figure 35 below shows the outcomes for the Project C, Hospital project considering all categories of the Work Sampling.

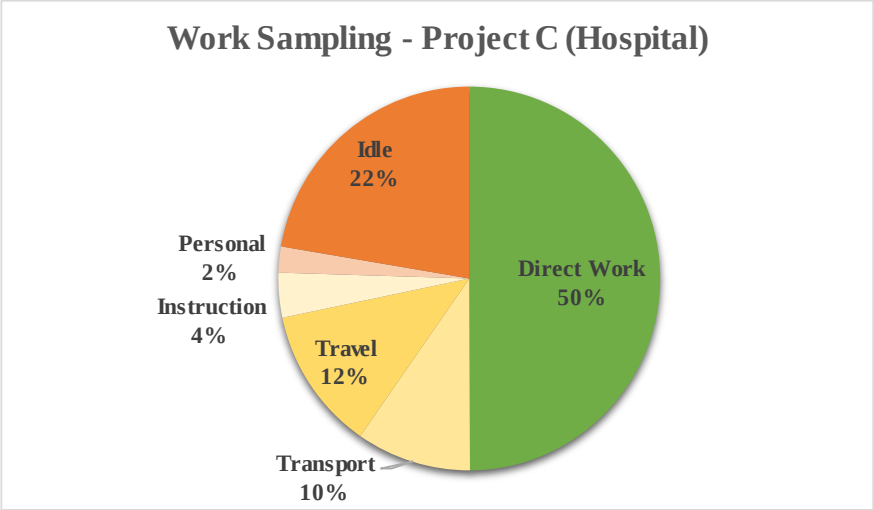


Figure 35: Work Sampling outcomes of Project C, Hospital project

Results comparison among three projects

The table 7 and the chart below (figure 36) compare the Work Sampling Analysis of the three projects (Project A, B and C) using the CFMx. It can be noted that there is a slight difference in direct work among them, indicating that the CFMx has the same outcome for different types of building construction projects. The charts of figures 30, 32 and 34 presented in the last section have demonstrated that for the interior finishes phase, the three projects presented almost the same direct work rate, which is about 50%. However, for the site development phase, a small variance of direct work rate between two projects can be noticed. While in Project A the direct rate varies from 44% to 56%, for the Project B the numbers vary from 55 to 57%.

	Project A – Multifamily Apartments		Project B - School		Project C - Hospital	
	Observations	**Results**	**Observations**	**Results**	**Observations**	**Results**
Direct Work	**3249**	**50%**	**1766**	**53%**	**821**	**50%**
Transport	492	7%	255	8%	160	10%
Travel	601	9%	354	11%	198	12%
Instruction	300	5%	155	5%	62	4%
Total Suportive	**1393**	**21%**	**764**	**24%**	**420**	**26%**
Personal	303	5%	112	3%	36	2%
Idle	1556	24%	677	20%	367	22%
Total Idle	**1859**	**29%**	**789**	**23%**	**403**	**24%**
Total	6501	100%	3319	100%	1644	100%

Table 7: Work Sampling outcomes of three projects using the CFMx

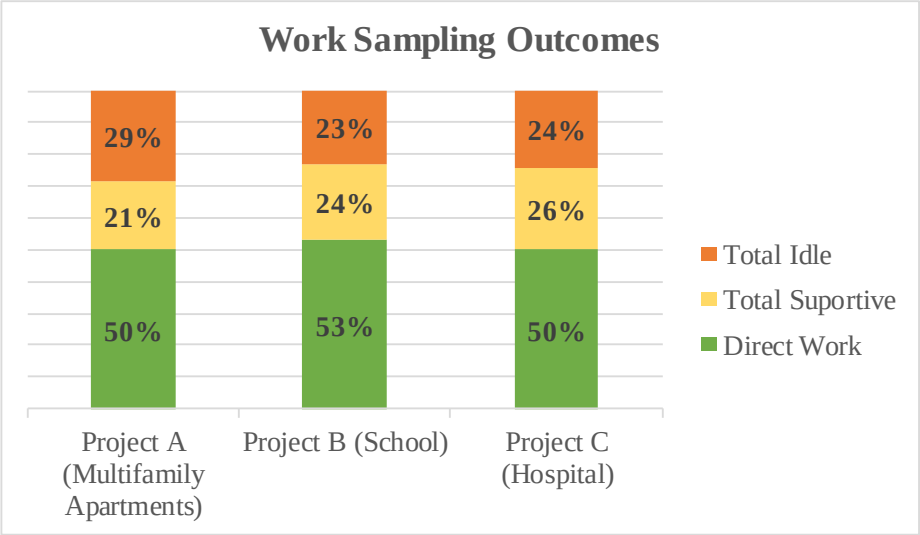


Figure 36: Work Sampling outcomes comparison among three CFMx projects

Comparison with the construction industry

Research conducted by Gong et al. (2010) reported Work Sampling data of 123 construction projects in the Austin, Texas region from 1972 to 2008. This study considered different types of projects such as commercial, highway, hospital, institutional, public and residential. During the period of 1972-1984, the Work Sampling had only two categories – direct work and nonproductive work. After 1985, six categories were used and has remained constant until date of the report. Although the segregation of categories used before was different from the actual, the data collected is still valid for analysis, since the central element is the direct work to be analyzed. This study was meant to reveal any sign of improvement of direct work ratio over 36 years (1972-2008). The research has detected an overall decrease trend, as shown the chart below (figure 37).

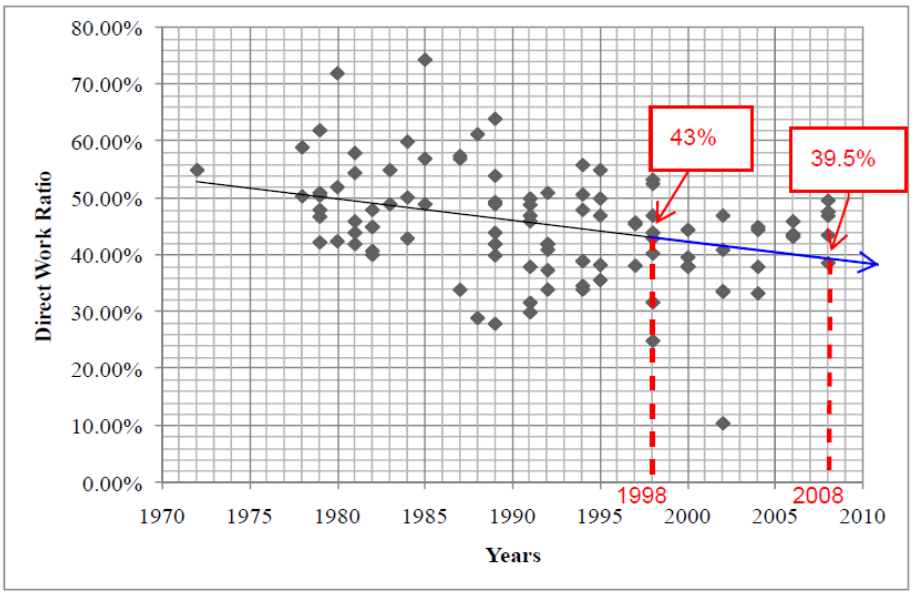


Figure 37: A chronologic view of Direct Work ratio (adapted from Gong et al.,2010)

The trend line shows that since 1972 the direct work decreases about 3.5% every ten years. For instance, in 1998 the direct work average was 43% and in 2008 (ten years later) this number decreased to 39.5%. If this rate continues for ten more years, the direct work from industry in 2018 will be 36% through projection of the trend line. Publications with Work Sampling results found in literature from recent projects could not be used to compare with the CFMx outcomes due to different types of projects (industrial projects) in other areas of the country. Therefore, the approach of using the tendency line was undertaken to estimate the current direct work for building construction projects. As the Work Sampling data from projects using the CFMx were collected in 2017 and 2018, a comparison between the CFMx and the industry for the same period can be performed. Table 8 below gives an average of direct work from projects using the CFMx, which is 51%, while the trend line gives an average from the industry of 36% for 2018. This means that the direct work ratio is 44% higher for the CFMx projects. The tables below shows the comparison between the CFMx projects and the average of these 123 construction projects from 1972 to 2018.

	Clear Flow Matrix Projects (2017-2018)	**Construction Industry Average (1972-2008)**
Direct Work	**51%**	**44%**
Transport	8%	11%
Travel	10%	14%
Instruction	5%	6%
Total Suportive	**22%**	**31%**
Personal	4%	5%
Idle	23%	20%
Total Idle	**27%**	**25%**

Table 8: Work Sampling results comparison between the CFMx and the construction industry average.

	Direct Work Ratio
Construction Industry Average (1972-2008)	44%
Actual Construction Industry Average in 2018 (trend line)	36%
Clear Flow Matrix Average (2017-2018)	51%

Table 9: Direct Work results comparison between the CFMx and the construction industry average.

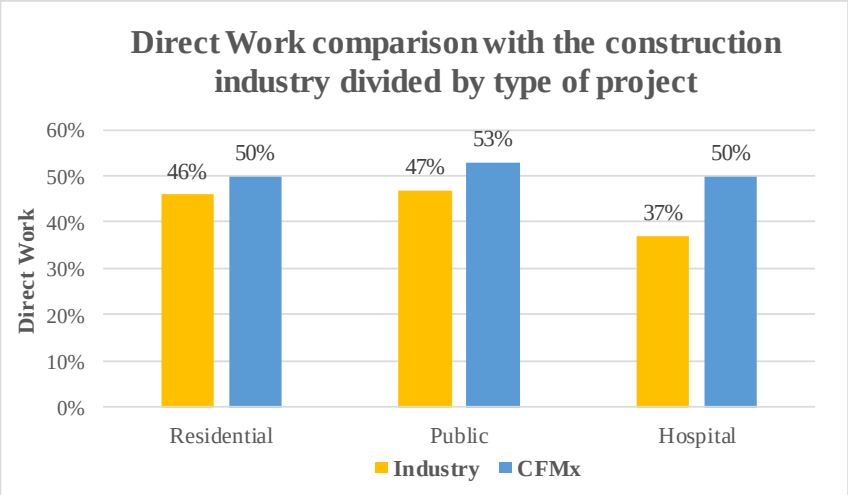


Figure 38: Direct work ratio comparison with the industry on three different types of project

The chart (Figure 38) and the table 8 above indicate that the direct work rate from projects using the CFMx is higher in comparison to the average of the industry. As stated before, the Work Sampling measures the effectiveness of craft time utilization in

construction, which is directly influenced by management techniques. Therefore, it is evident that better efficiency was found when CFMx was used in comparison to other techniques used in the industry, of which CPM may have been the most used tool on these projects. It is worth highlighting from the Figure 38 the high discrepancy of direct work ratio of healthcare projects, which is about 35% higher when using the CFMx. It can also be noted from the comparison outcomes that the supportive work (travel, transport and instruction) from CFMx projects is about 36 % less than the industry average. One possible motive for this is the clear representation of locations in each day that the CFMx gives to trade contractors. It helps improve the job site organization, making workers walk less to get their tools and materials.

Minimizing waste has been a key strategy adopted by Lean thinking to achieve project success. Work Sampling is a good indicator of waste in construction since it gives the percentage of time spent by workers on the four stages defined by Koskela, where only processing (direct work) is not considered waste in any production system. The CFMx assists project managers to manage their subcontractor trades by providing their exact location every day. Once the sequence of location is established, subcontractor trades can appraise the amount of work for each area and resources can be better coordinated, and consequently, waste is reduced.

Furthermore, as demonstrated earlier in this chapter, direct work represents flow efficiency or process flow. A smooth handoff process between trades is a vital element for achieving high flow efficiency. If areas are not ready for trades to perform their job, the workflow is interrupted, requiring workers from next trades to wait or to move to another spot. Consequently, workers should also transport materials, tools, and equipment to other locations as needed. All these consequences should be evident in the Work Sampling

outcomes. Management strategies play an essential role in handoff processes, which the CFMx controls on a weekly basis. Although the amount of handoffs during the project may increase due to short intervals (one week), this sets a homogeneous handoff duration and increases the plan reliability, since areas to be inspected may be smaller. This ensures that areas will be ready for next trades to come in, enhancing the flow efficiency of the project. This high flow efficiency is reflected in the high percentage of direct work of the Work Sampling Analysis.

QUESTIONNAIRE SURVEY

Questionnaires are one of the most traditional methods of collecting data, and consequently, researchers often use this technique in their studies (Rowley, 2014). In construction projects, a questionnaire survey is a powerful tool to get information about problems commonly encountered in construction job sites such as lack of communication, unreliable subcontractors, schedule delays, safety issues, lack of materials, among others. These problems usually affect labor productivity producing an adverse impact on the overall cost of the project. Construction companies can zero in on these negative points and mitigate them by interviewing their workers. Nobody knows better about these obstacles than construction workers. They come face-to-face with them on a daily basis and therefore are a good source of information, which project managers can take advantage of to overcome job site problems.

Interviews are considered essential to assess the effectiveness of the Clear Flow Matrix, which is a central topic of this research. Two types of questionnaires were created, one for the foremen and another for the project managers of the subcontractor trades. They are not the same but very similar. Foremen have an essential role in the construction

industry. They are the link between the project managers and craftsmen. Since some of the roles of the foremen include: coordinating tasks according to the schedule and plans; allocation of daily responsibilities; procuring the necessary tools and materials; their interviews are crucial to the evaluation of the CFMx on the daily construction management process. On the other hand, project managers are a more relevant source of information when the CFMx and CPM or other scheduling techniques are compared, which is also one of the research questions. Project managers might have had more experience with projects and at least with one type of scheduling technique they may have worked with before. Furthermore, project managers can provide information about the influence of the CFMx on the cost and profitability of projects. Therefore, foremen and project managers of trades subcontractors were selected to be interviewed.

However, to formulate a good questionnaire, that can answer the research questions is not an easy task. In the beginning, the questionnaire had 18 questions. After doing some interviews, it was noted that the questionnaire needed to be reduced. This reflects exactly what Rowley (2014) said in her paper about designing questionnaires, when she states that learning how to work with questionnaires is an iterative process. It means, while interviews are being performed, the researcher gets experience and may tweak the questions according to the responses received. Since the foremen were interviewed during their work, it was noted that they did not want to spend much time being interviewed. The time constraint was the first obstacle. The questionnaire should not have that many questions so that the workers could answer all questions within ten to fifteen minutes thereby not keeping them away from their job for long. If the questionnaire is too long, the workers tend to answer the last few questions faster in a bid to finish the interview quicker, thereby undermining the validity of the research. Furthermore, the second problem

encountered was the level of the questions. Out of these 18 questions, for some of them, the foremen had difficulty answering because a high level of engineering knowledge was required. Due to these two reasons, the number of questions were reduced from initial eighteen to a final list of thirteen questions. These problems were not encountered in case of project managers interviews, even though they contained only nine questions. The reason that the questionnaire for the project managers had fewer questions than the foremen was that project managers could not answer issues regarding daily operations such as overtime, rework and conflict areas with certanity since they are not regularly present at job sites.

In total nineteen foremen and seven project managers were interviewed during this research, encompassing as many different trades as possible. The foremen/superintendents were interviewed face-to-face on job sites while the project managers were interviewed either by telephone or in the LBCC office. Some project managers answered the questions in written format and sent them by email. The list of trades contractors and its respective projects are shown in the table 10 below.

Foreman/Superintendent

Trade Contractor	Type of Project
1 - HVAC	Multifamily Apartments, Buda – Texas
2 - Drywall	Multifamily Apartments, Buda - Texas
3 - Framing 1	Multifamily Apartments, Buda – Texas
4 - Framing 2	Multifamily Apartments, Buda – Texas
5 - Gypcrete	Multifamily Apartments, Buda - Texas
6 - Fire Alarm LV	Multifamily Apartments, Buda – Texas
7 - Painter	Multifamily Apartments, Buda - Texas
8 - Plumber	Multifamily Apartments, Buda - Texas
9 - Roofing	Multifamily Apartments, Buda – Texas
10 - LBCC supervisor	Multifamily Apartments, Buda - Texas
11- Mansory	School, Pflugerville
12 - Painter	School, Pflugerville
13 - Steel Frame	School, Pflugerville
14 – Dry Wall	Hospital, Roundrock
15 - Glazing	Hospital, Roundrock
16 - Plumber	Hospital, Roundrock
17 - Electrical	Multifamily Apartments, Waco – Texas
18 -Plumber	Multifamily Apartments, Waco – Texas
19 - Trim and Hardware	Multifamily Apartments, Waco – Texas

Project Managers

Trade Contractor	Type of Project
1 - Scheduler (LBCC)	Multifamily Apartments, Austin - Texas
2 - Drywall	Hospital, Austin – Texas
3 - Electrical	Hospital, Austin – Texas
4 - Pool	Multifamily Apartments, Buda – Texas
5 - Mechanical	Hospital, Kyle - Texas
6 - Turnkeys door and Trim	Multifamily Apartments, Buda – Texas
7 - MEP	Hospital, Andrews – Texas

Table 10: List of foremen and project managers interviewed

After doing several interviews, it has been noted understandably that the answers started to be repetitive. The cumulative count, which is the number of unique information received from interviews, had reached a diminishing return trend. This point indicates that even if further interviews were conducted, no additional new information would be

collected (Wang & Leite, 2016). The repeated answers can be seen in the table 11 below, which shows some answers from foreman and project managers about the benefits of the CFMx. However, the interview continued to be performed to collect more data for the quantitative questions. As the outcomes of the quantitative questions are demonstrated in numbers and consequently in charts, a large number of interviews would bolster the validity and therefore the conclusion of this research. For the qualitative questions, in which the outcomes are text and cannot be measured, the answers were summarized and presented in tables.

QUESTIONNAIRE SURVEY´S OUTCOMES

Since 26 people were interviewed and the foremen questionnaire had thirteen questions, and the project manager questionnaire had nine questions, the amount of answers obtained from questionnaire was enormous. To better assess these answers, the thesis created 8 main topics and answers were associated with each to of these topics.

The topics are:

1. Benefits and improvements of the Clear Flow Matrix
2. Comparison between the Clear Flow Matrix and CPM or other scheduling methods
3. Crew size coordination
4. Trade-stacking conflicts
5. Rework
6. Overtime
7. Productivity improvements
8. Drawbacks and challenges of the Clear Flow Matrix

The following sections will show the results obtained from the interviews for each topic above.

Benefits and Improvements using the Clear Flow Matrix

The first topic presented is to demonstrate how the Clear Flow Matrix can improve construction projects. The table 11 below presents a summary of the answers from different trades contractors collected from the interviews. As mentioned in the previous section, some responses from different trades are very similar, proving the enough amount of interviews conducted.

Trade Contractors	**Type of Project**	**Benefits and improvements using the CFMx**
Electrical	Multifamily Apartments, Waco – Texas	• The Matrix gives the location and the dates that trades have to work.
Trim and Hardware	Multifamily Apartments, Waco – Texas	• It is easy to understand the future jobs that are coming to be performed.
Plumbing	Multifamily Apartments, Waco – Texas	• The CFMx is very easy to understand.
HVAC	Multifamily Apartments, Buda – Texas	• The CFMx presents the whole schedule with all trades involved in the project. • The CFMx has a good visual presentation. • Superintendent knows every day where their crew has to work. • The matrix gives foremen previously the amount of work that their workers will have in the following weeks. It helps coordinate their crew and improves the productivity.

Table 11: Answers from foremen and project managers about benefits and improvements using the Clear Flow Matrix

Roofing	Multifamily Apartments, Buda – Texas	• The CFMx gives information where trades should be working.
Framing	Multifamily Apartments, Buda – Texas	• The CFMx gives clearly all the dates of the project. • Using the CFMx you can forecast the amount of work in the next days.
Fire Alarm and LV	Multifamily Apartments, Buda – Texas	• The CFMx compresses the whole schedule of the project in one single page.
Gypcrete	Multifamily Apartments, Buda – Texas	• The matrix has rendered the job easier because the areas are ready to me and I can start to perform my work. • The CFMx makes also the project more organized.
Dry Wall	Multifamily Apartments, Buda – Texas	• CFMx helps keep the schedule of the project on time.
Plumber	Multifamily Apartments, Buda – Texas	• The CFMx makes the job go faster. You can reduce the time of the project.
Project Manager – Swimming Pool Construction	Multifamily Apartments, Buda – Texas	• CFMx has minimized the amount of phone calls or emails needed to coordinate start dates and/or turnover dates. Less chaos amongst other trades. • The matrix tells everyone universally what needs to be done and when it needs to be complete.
Project Manager – Turnkey doors and Trim	Multifamily Apartments, Buda – Texas	• The CFMx helps us understand the overall length and relative scope for us and what trades are involved before and after.
Project Manager –Dry Wall	Hospital, Austin – Texas	• CFMx shows exactly the location of each trade in the project.

Table 11 continued.

Painter	Multifamily Apartments, Buda – Texas	• The CFMx shows the schedule in only one page
Superintendent of LBCC	Multifamily Apartments, Buda – Texas	• The CFMx helps the company as a communication tool. The status of the schedule can be easily identified.
Plumber	Hospital, Round Rock – Texas	• CFMx provides good planning, and the projects become more organized. • Foremen know every week the amount of work and the location that their crew will have. It helps them to coordinate their crew.
Glazing	Hospital, Round Rock – Texas	• It is a daily update. The CFMx gives the status of the project in regards schedule very quickly. It is also straightforward to identify the locations that workers need to be.
Steel Frame	School, Pflugerville – Texas	• The matrix avoids miscommunication between trades and G.C, because everybody is involved. • The CFMx accelerates the process to build better and right.
Masonry	School, Pflugerville – Texas	• More areas are ready to start the job, improving the productivity.
Project Manager – LBCC	Multifamily Apartments, Austin – Texas	• The CFMx decreases the work to create the schedule and to update it.
Project Manager – Mechanical	Hospital, Kyle – Texas	• Improves the productivity and workflow are maintained and incrementally managed.

Table 11 continued.

From the answers above, it can be concluded that the CFMx has some key beneficial aspects:

1. Understandable: The CFMx presents in a very easy way the schedule. Everybody can understand the functioning of the matrix. No engineering knowledge is required to grasp the CFMx.

2. Communication: The CFMx improves the communication among all the project participants. All schedule come together in a single page that can be easily communicated to all levels of project supervision and support.
3. Everybody is involved: This is a consequence of the benefits number 1 and 2. The CFMx is an intuitive technique and every trade can follow the whole schedule without difficulty. Foremen can track the project without needing assistance from project managers.
4. Easy to manage: There is no need for an advanced software to use the CFMx. Only excel spreadsheets are required. The process of updating the schedule is very fast and easy.
5. Location: The CFMx shows all trade contractors where their crew is supposed to be working every day.
6. Forecast the amount of work: The CFMx presents all the locations and the dates of each activity. Thusly, trades supervisors can estimate ahead of time the amount of work of each week of the project until the completion date. This helps trades supervisors coordinate their crew size.
7. Schedule on time: Once everybody works at the same pace, it makes the project more organized and keeps the schedule on time.

Below, some quotes are presented about the CFMx from interviews.

The CFMx improves the way that you can organize things. It improves also the communication between trades and contractor. The whole schedule is represented in an single page (Foremen from steel frame trade, school project Pflugerville).

Using the CFMx everybody works at the same pace and therefore it helps keep the schedule on time. (Foremen from dry-wall trade, Multifamily Apartments project).

Comparison between CFMx and other scheduling techniques

This section shows some answers (table 12) what the foremen and project managers say about the CFMx in comparison to other scheduling tools used before in other projects.

Trade Contractors/Project	**Scheduling Method used before**	**Comparison with CFMx**
Electrical / Multifamily Apartments, Waco – Texas	CPM-Bar Chart	• There is no much difference between these two methods. Because the only information needed is the start and finish dates. • CPM Bar-Chart is easier to understand.
Trim and Hardware/ Multifamily Apartments, Waco – Texas	CPM-Bar Chart	• CFMx is better than CPM. • CPM is easier to understand.
Plumbing/Multifamily Apartments, Waco – Texas	CPM-Bar Chart	• Not much difference between them. • CFMx is better because foremen/project managers can easily see the finish date of the project. • The matrix is easier to understand than Bar-Chart.
Framing / Multifamily Apartments, Buda – Texas	CPM-Bar Chart	• The CFMx is easier to understand. We can see what building and what date we have to be working.. • The scheduling of CFMx is more organized.
Fire Alarm and LV / Multifamily Apartments, Buda – Texas	CPM-Bar Chart	• The CFMx is easier to understand and better to follow the project. • Bar Chart is less organized and easier to be out of the sequence.
Gypcrete / Multifamily Apartments, Buda – Texas	CPM-Bar Chart	• Bar Chart is easier to understand because I am more familiar with.

Table 12: Answers from foremen and project managers comparing CFMx and other techniques

Plumber / Multifamily Apartments, Buda - Texas	CPM-Bar Chart	• CFMx is easier to understand • CFMx gives you more detail about the schedule and it is more sophisticated.
Project Manager – Swimming Pool Construction	CPM-Bar Chart	• CFMx is easier to understand and grasp. • CPM accurately displays the schedule but is scattered around. CFMx is better because everything is complete in waves and is easier to read quickly.
Project Manager –Dry Wall	CPM-Bar Chart	• The CFMx is more exact. Bar Chart has a broader look. • CFMx is better and more understandable. • Using the CFMx , the areas have about the same size. On the other hand, the areas of CPM are not homogeneous.
Project Manager – Electrician	CPM-Bar Chart	• CFMx is more specific than CPM
Painter / Multifamily Apartments, Buda – Texas	CPM-Bar Chart	• The main difference is the representation. The CFMx shows the schedule in one single page. • CFMx is easier to understand than CPM.
Superintendent LBCC / Multifamily Apartments, Buda – Texas	CPM-Bar Chart	• CPM is more detailed. • However, the CFMx does a way better job of assessing where the project currently is. • The Subcontractor understands better the CFMx than CPM.
Glazing / Hospital, Round Rock – Texas	Pull Plan – Last Planner System	• The CFMx is more visual than others, and everybody can see the whole schedule improving the communication among the trades. Projects can be better tracked using the CFMx. • CFMx is easier to understand.
Plumber / Hospital Round Rock – Texas	CPM-Bar Chart	• CFMx is easier to understand, because the whole schedule is shown in a single page.
Dry Wall / Hospital, Round Rock – Texas	CPM-Bar Chart	• Some projects did not have any scheduling tool; the communication was verbal. Some projects CPM was used. • CFMx is better and easier to understand.

Table 12 continued.

Masonry / School, Pflugerville	Pull Plan (Last Planner System)	• Not much difference between them. • Pull Plan is easier to understand because I am more familiar with.
Steel Framing / School, Pflugerville	Pull Plan (Last Planner System)	• Pull-Plan (Last Planner System) is more detailed. • CFMx is easier to understand.
Project Manager Turnkey doors and Trim / Multifamily Apartments, Buda-Texas	CPM- Bar Chart	• Both can be helpful once is understood what the chart is representing. However, the CFMx presents information in a way that is easy to understand.
Project Manager / LBCC	CPM-Bar Chart	• The CFMx communicates better the schedule and its status such as how far ahead or behind is the project. CFMx represents very clear the whole schedule. • The CFMx has a binary outcome. Either the activity is done or not done. • CFMx is visually more straightforward to understand. Usually, the subcontractors do not understand well the CPM.
Mechanical / Hospital	CPM- Bar Chart	• The main difference is that CFMx tracks the project in daily-weekly basis while the others are a monthly basis.

Table 12 continued.

The answers above conclude what the literature review says about CPM that is the widest used tool for scheduling. From twenty-seven people interviewed, the majority of them knew or worked before with CPM. Four foremen could not compare the CFMx because they have not had contact before with any scheduling technique.

The most important difference for them between the CFMx and CPM Gannt-Chart is the representation of the schedule. The answers strongly pointed out that the CFMx is much more understandable and easier to work than CPM. Using the CFMx, the whole schedule is compressed in one single page, facilitating the involvement of all workers in

the schedule. However, a few people prefer CPM or Last Planner because, according to their answers, they are more used to them and not because these methods are more effective than the CFMx. Regarding the level of detail, most of the people stated that the CFMx is more detailed than CPM. One question of the questionnaire was about the level of detail of the CFMx, if the this technique presented enough detail to be a good scheduling tool. All the respondents answered yes. Below, there are some quotes about the comparison between these two methods.

> Below, some quotes are presented about the CFMx from interviews.
>
> I have worked before with Bar Chart. CFMx is easier to follow. The main difference in comparison to Bar-Chart is that the matrix compresses the whole schedule in one page (Foreman from fire alarm and low voltage company, 2018).
>
> At a personal level, with the matrix I have a lot less work to create and manage a schedule. The workload decreased significantly for scheduling. For instance, I have a 50 million dollar project with more than 150,000 sq/ft, five different building groups, four-story park garage, etc. It is a very complicated project. If I would have created a CPM schedule project for it, it probably would take me two solid weeks, and I took less than a day to schedule using the Matrix. So, the CFMx decreases the work to create the schedule and also to update it. (Project Manager from LBCC, 2018)

Coordination of crew size and resources

The section will present if the Clear Flow Matrix help the coordination of crew size and resources. Some answers from the foremen and project managers are shown in the table 13 below.

Trade Contractors	Project	Does the CFMx help the Coordination of crew size and resources?
HVAC	Multifamily Apartments, Buda - Texas	• Yes, the matrix gives previously the amount of work that trades will have in the following weeks. Superintendents can manage better their crew
Gypcrete	Multifamily Apartments, Buda - Texas	• No. It does not matter if it is Bar-Chart or Matrix to manage the crew size.
Project Manager / Electrical	Hospital, Austin - Texas	• Yes. One of the main strong things of the clear flow matrix is the crew size. The matrix shows exactly the amount of work for the following weeks.
Project Manager / Dry Wall	Hospital, Austin - Texas	• Yes, the CFM breaks the areas with almost the same size, you will have the crew size, material, resources also pretty much the same for the whole project .

Table 13: Answers from foremen and project managers about crew size

Below, some quotes are presented about the CFMx from interviews.

> Because at any time the CFMx provides an accurate schedule, it helps the Subs to put their resources in that project and coordinate with other projects. For example in this project using the CFMx I can look ahead a year from now and know exactly where each trade contractors have to be working and the amount of work that they will have. It helps a lot to coordinate resources. There is no way to pull out this information in traditional scheduling (Project manager from LBCC)

> CFMx provides a better planning and the projects becomes more organized. I know every week the amount of work that I will have and the location. It helps me to coordinate my crew. (Foremen from dry-wall trade, Round Hospital Project)

The table 13 above demonstrate that the CFMx helps the trade subcontractors to coordinate their crew sizes. The CFMx presents the schedule in a simple way in which superintendents may forecast the amount of work accurately for the entire project, allowing them to manage their resources according to the work demand. Subcontractor trades may

receive the schedule before starting their work, that is they have prior knowledge as to where and when their respective crews need to be for the whole project. For each trade, the amount of workload may vary from area to area, which the superintendents can identify by looking at the workspace division in the CFMx. The CFMx exactly meets the appropriate model of resource requirements elaborated by Birrell (1980). The author states that ideally resources must pass through different locations in the same sequence. By managing construction projects in single sequence, it may facilitate the trade contractors to plan their work and procure materials and also improves the communication among all project participants (Birrell, 1980).

As mentioned earlier, the trades need to finish the work in their specified area in a one-week duration, based on which the superintendents can adjust their crew sizes of each week of the project. Additionally, the CFMx may also assist project managers to coordinate their resources within different projects. As it is well-known that subcontractors companies can have many projects occurring simultaneously, the coordination of crew size among those projects becomes an important issue. According to O'Brien (2000), the key component to achieve project flexibility is the ability of subcontractor trades to shift their resources in different contracts.

However, disruptions and change orders causing schedule delays are very common in construction projects, which may also cause changes in the crew size and resources estimates. But, it is worth noticing that schedule updating process using the CFMx on a weekly basis is very simple which the superintendents can easily follow and subsequently update their resource estimates. The figure 39 below illustrates the answers from respondents about the coordination of crew size.

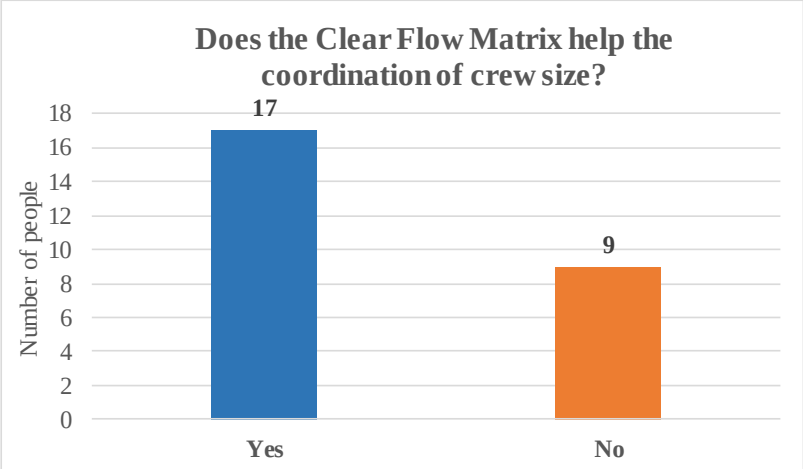


Figure 39: Outcomes about the CFMx and crew size coordination

Conflict Areas

Vast amount of research has demonstrated that congestion in the workspace is an adverse factor with respect to labor productivity in construction. Working out of sequence, idle time, working in restricted areas and waiting time are some of the problems derived from stacking of trades or congested areas that negatively affect productivity. It is very common to associate stacking of trades with schedule acceleration when contractors try to catch up with the as-planned schedule inserting more workers or assimilating different trades in the same workspace. However, a study conducted by Thomas et al. (2006) concluded that congested work areas might occur as a result of multiple factors other than just schedule acceleration. Under normal circumstances, projects can have stacking of trades due to poor planning too. Contractors can eliminate stacking of trades due to the above reason by coordinating their trades contractors properly and using a good scheduling technique.

One of the main questions in the interviews addressed the topic of stacking of trades, where the foremen were asked if they have to wait often, or move to another location because of another trade contractor occupying that same workspace. Looking at the chart below (figure 40), it is evident that CFMx is a technique that helps avoid this unwelcome situation. Only one person said that he often needs to wait or move to another spot. Unfortunately, it was not possible to compare this data with the average of trade stacking encountered in the construction industry as no data was found demonstrating the frequency of stacking of trades in job sites. The favorable answers to the above question reflects the scheduling transparency that CFMx provides for project managers of the GCs. As mentioned earlier, the CFMx shows the location of each trade every week, undoubtedly making the management of subcontractors trades easier than with other scheduling techniques.

Not only that explicit representation makes the CFMx a powerful tool for project coordination, but also the fact that the concept of takt time, another strong element, is embedded in the CFMx helps enhance the organization of the project. The takt time and the location breakdown structure forces all trades to work at the same pace which leads to achieving a continuous workflow without contributing to any stacking of trades. As demonstrated earlier by Sacks (2016), the ideal workflow occurs when all trades have uniform takt time in the location areas and each trade occupies only one location during the same takt time. That is exactly what the CFMx strives for and achieves.

Figure 40: Outcomes about the CFMx and conflict areas

Rework

Rework is another obstacle for achieving continuous workflow and an adverse factor for labor productivity that affects both schedule and cost. According to CII (2005), the average cost due of rework is 5% of total project cost. Rework in construction occurs when trades need to come back to the same location and perform the same work that has been performed earlier due to nonconformity with requirements and standards. Many factors may lead to rework on job sites, such as owner scope changes, design errors, procurement errors, damage from other trades, poor management techniques, and poor construction operations, to name a few. A study conducted by Fayek et at. (2003) indicates that the leading cause of rework for industrial projects is "Engineering Reviews" with approximately 55% of rework cases. This category, for instance, includes the following items: late design changes, errors, and omissions, scope changes and poor document control. In this research, the authors ranked the category of "Construction Planning and Scheduling" as the fourth most important factor with 2.47% of rework cases. Another study conducted by Love & Li (2000) for building projects confirms that design changes are the primary cause of rework for about 54% of total rework costs.

The CFMx is a production control technique that helps the identification of design errors and consequently design changes before the project reaches an advanced stage. It is obvious that identifying and rectifying these design errors as early as possible will cause less of an impact on construction job sites. In repetitive construction projects such as building projects in general, trade contractors repeat the same work multiple times in different locations. Once one trade finishes one area and moves to another spot, the subsequent trades come in to continue the work in that area. The size of the released area from previous trade is defined as batch size. The size of these areas may affect the performance of the project in many aspects. In construction, it is common to see large batch sizes, so that trades can continue the same activity for long as possible. However, some researchers have demonstrated that small batch sizes can bring some advantages, such as reducing the duration of the project, reducing the WIP inventory between two trades and detecting defective products or work earlier (Shim, 2011). This last one is related to how the CFMx can reduce the rework rate in construction projects. Once the CFMx breaks down the area of the projects into smaller batch sizes, design errors or defective works can be identified early. By having smaller batch sizes, design errors can be diagnosed for that particular area which could in fact be present in other areas too. Therefore, engineers or architects can review these errors for those other areas before trades come in, reducing the amount of rework. The interviews show this reduction of rework in projects that CFMx has been used. The chart below (figure 41) presents the outcome of this interview, in which about 44% of respondents stated a reduction of rework.

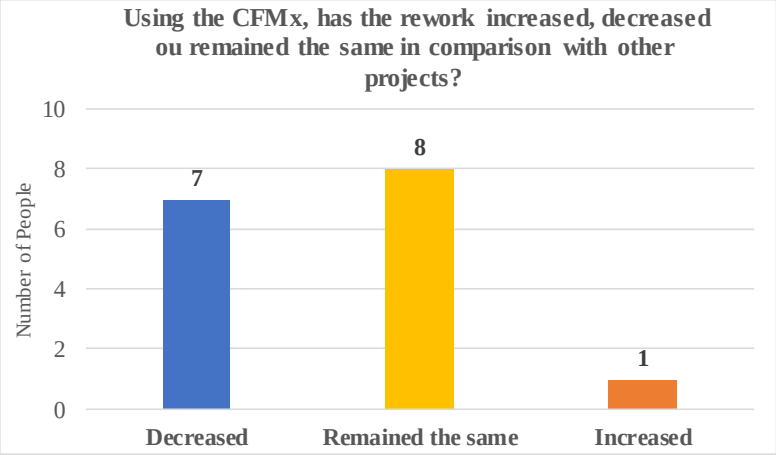


Figure 41: Number of answers about the CFMx and rework

Overtime

Overtime, overmanning and shift work are the main actions taken from contractors to catch up the as-planned schedule when projects are delayed. However, disadvantageous factors arise when craftsmen work overtime on construction job sites. Not only the obvious aspect of increase in the project cost, but also problems with respect to reduction in productivity and quality, increase in the risk of accidents and increase in absenteeism and turnover.

A good production control system, which assists projects to be on track, prevents the necessity to apply the overtime strategy. As mentioned earlier, the CFMx uses small batch sizes in its procedures that allows the weekly-basis scheduling update. Contractors and subcontractor trades can obtain the scheduling status of the project in a very short interval of time, which allows the projects to avoid having scheduling slippage. As trades can visualize each week with respect to how far behind they are in the project, small actions are required to mitigate the delay problems. For instance, if one trade is only one week behind, it is identified instantly in the CFMx and short overtime period or a little

overmanning is required to be on par with the as-planned schedule. This usually does not occur using CPM technique, due to a complicated process for schedule updating. The answers from foremen reveal the efficiency of the CFMx to reduce overtime in construction projects. More than 50% of respondents said that they noticed the reduction of overtime in projects where the CFMx has been used. Only one person mentioned having an increased overtime, from the framing trade from Multifamily Apartments project. According to him, the reason for this increase is due to the necessity to be always on time with the schedule in that project. This answer demonstrates that CFMx compels the commitment of trades with the schedule. The figure 42 shows the outcomes about overtime in projects where the CFMx has been used.

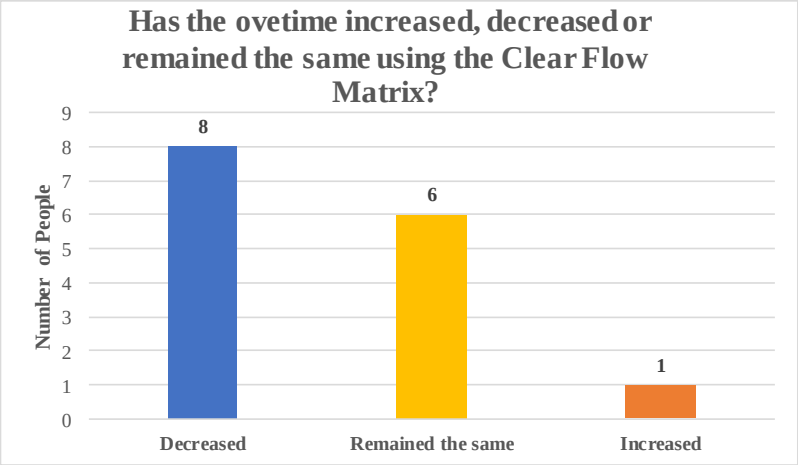


Figure 42: Outcomes about the CFMx and overtime

Productivity Improvement

One question of the questionnaire was about productivity improvements using the Clear Flow Matrix. The chart below indicates that the CFMx has enhanced the productivity

of subcontractor trades. According to the interviews with foremen and project managers, about 85% of respondents stated having productivity improvement in comparison to other projects (see figure 43).

Studies have showed that several factors may affect the productivity on construction site including rework, overtime and congested areas. These factors were discussed prior in this chapter and the interview data have demonstrated improvements on these three issues using the CFMx in construction projects, which bolster the outcome of productivity question. Moreover, a study conducted by Liou & Borcherding (1986) proved that the direct work from Work Sampling Analysis results can be an estimator for productivity rate. The close relationship between Work Sampling and productivity is verified in their research. This is also one more evidence that CFMx enhances the productivity on construction projects, since the high percentage of direct work rate was obtained in projects using the CFMx, as sown in earlier on this chapter.

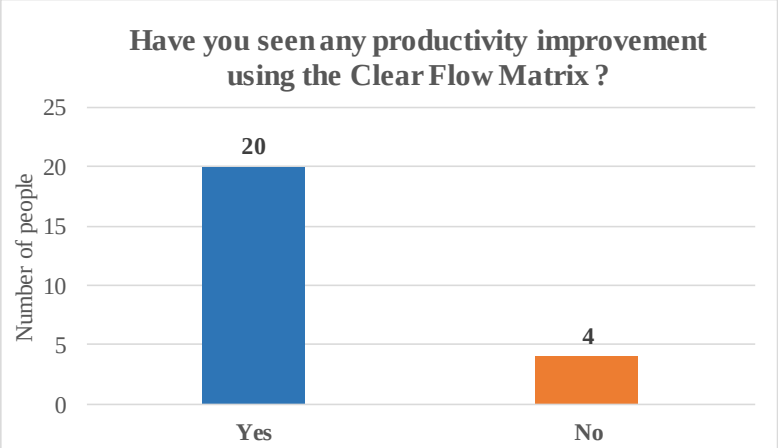


Figure 43: Outcomes about the CFMx and productivity

Drawbacks and Challenges of the CFMx

The table 14 below shows some answers what the foremen and project managers said about some drawbacks and challenges of the CFMx.

Trade Contractors	**Project**	**Drawbacks and Challenges of the CFMx**
Roofing	Multifamily Apartments, Buda – Texas	• It is not perfect because of the weather conditions. The matrix does not take into account the weather days; it means that the dates are not changed according to weather conditions.
Steel Frame	School, Pflugerville	• CFMx is generic and not much detailed.
Plumber	Multifamily Apartments, Waco – Texas	• The weather condition is a big problem of the CFMx. If the weather is too cold, for instance, the CFMx ignores it, becoming hard to follow the the schedule. If there weren´t weather problems, the CFMx would be really good.
Electrical	Multifamily Apartments, Waco – Texas	• If one trade is behind, it pulls the other following trades back, causing a chain reaction. • The CFMx micromanages the job. I know the best and cheapest way to do the job, but with the CFMx I cannot perform in that manner.
Plumber	Hospital, Round Rock – Texas	• The pace of the CFMx is faster than usual.
Project Manager – Dry Wall	Hospital, Austin – Texas	• If there is a sub that is not following the Matrix, it affects the other trades behind it.
Project Manager – LBCC	Multifamily apartments	• It still have to have the weekly meetings in the handoffs process to talk about all the little details. The CFMx does not spell out every single activity on its presentation. • Digitalize the use of the CFMx in job sites instead using a piece of paper.
Superintendent – LBCC	Multifamily Apartments, Buda - Texas	• The CFMx does not represent all the information to manage projects. • The CFMx is too generic.

Table 14: Answers from foremen and project managers about challenges and drawbacks of the CFMx

The table above describes some statements from foremen and project managers about flaws and challenges of the CFMx. Although the data collected have shown many benefits of this technique, the interviews also uncovered mainly weaknesses, which reach both subcontractor trades and contractors.

Weather days: Some respondents reported that the CFMx does not consider weather days in the schedule. The dates represented in the cells do not change throughout the project. Once the schedule is elaborated, no changes on the dates in the matrix are permitted, even with the occurrence of force majeure. If the schedule delays due to weather conditions, contractors do not consider it and subcontractor trades have to take actions to catch up the original schedule. However, the CFMx assumes time buffers embedded in some activities, which serve as weather contingency. For instance, the pacesetter activity insulation may not need one-week duration to install the product in the breakdown areas. This buffer occurs also on the inspection activity, which requires only one day to be performed. Therefore, the CFMx recognizes the possibility of weather days, but it is not showed explicitly in the matrix.

Chain reaction and pace of the CFMx: Another comment from the respondents refers to the chain reaction when one pacesetter activity is delayed, which produces bottleneck activities in the system. If one trade delays, all other subsequent trades are compelled to reduce their pace or sometimes completely stop their work. This is because of the correct sequence of activity that the project must follow, where one trade cannot get ahead of the next trade in the sequence. Although this protocol must occur in all construction projects, the chain reaction for subcontractor trades may become a significant drawback using the CFMx, due to the previous activity that releases to the next trade only one area (batch) each week. As mentioned earlier, the batch size in the CFMx is small,

ensuing that not many areas will be ready for the next trades to work in. In other words, there are no buffer areas available for trades. Therefore, the trade that is not working at the pace of the schedule, it becomes the bottleneck of the project, forcing the next trades to reduce the speed of their work. This claim reflects exactly what the literature review stated, that subcontractor trades strive for high resource efficiency or operations flow. They want to use their resources as much as possible and do their work at their most convenient pace. They do not recognize the concept of critical WIP and that everybody must work at the same pace to achieve high flow efficiency improving the performance for the whole project.

Level of information: Some foremen and project managers stated that the CFMx does not spell out all the information needed to manage construction projects. However, the high level of detail of a schedule does not automatically translate to the plan having the best approach. Birrell (1980) advocates that the plan should not be too detailed as it may become harder to manage and could cause confusion instead. The overall plan must have enough detail so that the trade contractors can plan their work the best they can. Once trade contractors are hired to perform the work, their supervisors should develop a more detailed plan of work. They usually have vast experience in their specialties and may know the fastest and optimal manner in which to build, more than anyone.

One question in the interviews was about the level of detail of the CFMx, which most of the respondents said that the technique has enough detail to be a good scheduling tool. Although the clear representation of schedule using the CFMx is one of its the strongest assets, only spreading out the matrix in a piece of paper to subcontractor trades does not assure that the project will be well managed. Project managers must set up weekly

meetings with all trades to discuss the project in further detail. Below a quote from Birrel (1980) about level of detail.

> Not too many details should be loaded onto the plan because if that is done, the plan will sink in the mess of details. The overall plan should stand out by itself and show the details to be handled by each responsible participant in the construction team (Birrell, 1980).

Chapter 5: Conclusion

The first chapter of this thesis presented two research questions for this research to address through review and analysis of the data collected, contributions and recommendations for future research.

RESEARCH QUESTIONS

Through Work Sampling Analysis, the thesis will assess the effectiveness of the Clear Flow Matrix and compare its performance with the production rates achieved using more traditional scheduling and production control systems.

The thesis considered two approaches to evaluate the effectiveness of the CFMx, Work Sampling Analysis, and Questionnaires/Interviews. Measuring labor utilization is one approach used to measure the effectiveness of a management technique for construction projects. This is exactly what the Work Sampling Analysis does. This method depicts how workers are spending their time on job sites. The second approach involves questionnaires/interviews, where foremen and project managers from trades contractors answered some questions about the CFMx.

The literature review in chapter 2 indicated that two axes compose production systems: Flow efficiency or process flow and resource efficiency or operations flow. These two types of flow need to be balanced in a high efficiency so that the whole system can also achieve high efficiency. However, flow efficiency is not easy to grasp for construction projects and to measure it is even harder. Therefore, focusing on high resource efficiency has been the standard approach for organizations to be more efficient. This thesis connected the TFV theory from Koskela, the Shingo´s and the Modig & Åhlström's view about production with Work Sampling Analysis and concluded that Work Sampling measures

the flow efficiency in construction projects. The more direct work percentage collected, the better the flow efficiency of management technique will be.

In the chapter 4, it was shown a comparison of direct work ratio between CFMx projects and the construction industry average. A higher direct work ratio of the CFMx indicates a better efficiency in comparison to other techniques used in the industry. According to (Modig & Åhlström, 2016), by focusing on flow efficiency, companies can reduce waste and superfluous work, which also improves resource efficiency. The use of a management technique which focuses on flow instead of trying to maximize resource utilization as much as possible is the correct path for companies to improve their efficiency. This might be one reason why CFMx has presented high percentage of direct work or high flow efficiency. The exact location given daily by the CFMx and the weekly handoff process are the core factors for this workflow improvement. Trades contractors know every day where their crew is supposed to be working and are able to work five days uninterrupted in their areas before having to hand it off. Furthermore, the small and homogeneous work areas improve the handoff process, since the work inspection is reduced and becomes more accurate, assuring the areas will be ready for next trades.

The interviews also show positive outcomes of the CFMx. The improvement of productivity is the strongest point uncovered from the answers. Rework, overtime and overcrowded areas are work conditions, which reduce work effectiveness and these topics were discussed during the interviews. The answers from the questionnaires of foremen on job sites indicates a decrease of these three topics, which provided a positive impact on productivity. It also reveals that management techniques in construction projects influence the productivity of trade contractors. In construction projects, project managers of the GC do not have the ability to manipulate the efficiency of trade contractors, known by Shingo´s

view as resource efficiency, which is the responsibility of trades supervisors. However, to coordinate the handoff process, general contractors through their management expertise have total accountability, which is known as process flow by Shingo. The Balanced Workfront of the CFMx balances these two types of flow in projects providing the minimum WIP necessary to meet the as-planned master project schedule completion date. In other words, the Balanced Workfront balances production requirements or quantities of work against the processing capacities of the trade contractors on the project.

Describe the Clear Flow Matrix in its daily management process and compare to other traditional techniques of construction management.

The answers from questionnaire verifies that the majority of companies still use only CPM network analysis and its embedded Gantt chart view as a tool to manage construction projects and required field production. From nineteen foremen interviewed, only three of them have been using other techniques available in the marketplace. Few foremen stated that they have not had contact with any type of production control system or scheduling tool. Results of application of this commonly applied approach are dependent on the "buy-in" of the trade contractors and their frontline supervisors. Among the many flaws of this common CPM approach presented in the literature review in chapter 2, the format of the presentation of schedule is one of its most problematic deficiencies. The use of a detailed Gantt-chart of suitable detail for production measurement and control typically requires numerous pages of documents in order to schedule the complete project from the start through all trade work and then to completion. This amount of information is difficult for all trade supervisors and field personnel to interpret and update throughout the duration of the project. Thus, control of production in the field that maintains the master

project schedule requires significant management resources to update and maintain specific time-oriented production plans in the field. In today's building construction industry most field production work is undertaken and managed by trade contractors rather than by direct-hire employees of general contractors or construction managers.

Effective management of this "trade contractor" marketplace requires that all project schedules from the master schedule through the most detailed production schedules should encourage the effective involvement of managers, supervisors, foremen and trade workers. In many applications of the commonly employed CPM network and Gantt-chart technique, the general contractor or construction manager project personnel communicate the start and completion dates from the master schedule to the trade contractor supervisors and foremen and then the trades are encouraged to work together to complete the project.

Answers from interviews demonstrated that the CFMx breaks this protocol typical of the building construction industry by providing to all personnel involved in the building project, not only the CPM schedule in a single page, but an easy and intuitive production management and control system, which assists trade supervisors and foremen to coordinate their crew sizes in accordance with the work demand required to complete the project according to the master CPM schedule. Differing from CPM, where often only schedulers and project managers from the GC or construction manager see and understand the CPM schedule, the CFMx is a management technique that encourages the use of the schedule by all project participants and provides a simple and straightforward process for production management on a weekly basis. Moreover, the CFMx requires no advanced software, only spreadsheets, while CPM MS projects or primavera are needed in a daily management process.

The CFMx through its Balanced Workfront view of production management and control is a different and practical approach for depicting CPM master schedules and required production in a condensed format that is effectively utilized by senior management, trade contractors, trade supervisors and trade workers.

Contributions

This thesis contributes to building construction industry, which still is plagued with high-frequency cost overruns due to scheduling delays. Contractors can overcome such problems by applying existing management strategies. However, either many of these techniques are not suitable for building construction or engineers cannot apply them appropriately to their projects. This thesis presents a new technique, entitled the Clear Flow Matrix, which is very easy and intuitive to use. Moreover, assessment of this new technique was performed, and therefore, this thesis contributes more specifically to Lott Brothers Construction Company, which created the Clear Flow Matrix.

Recommendations

This research can be extended with three more topics, which were not discussed in further detail in the thesis.

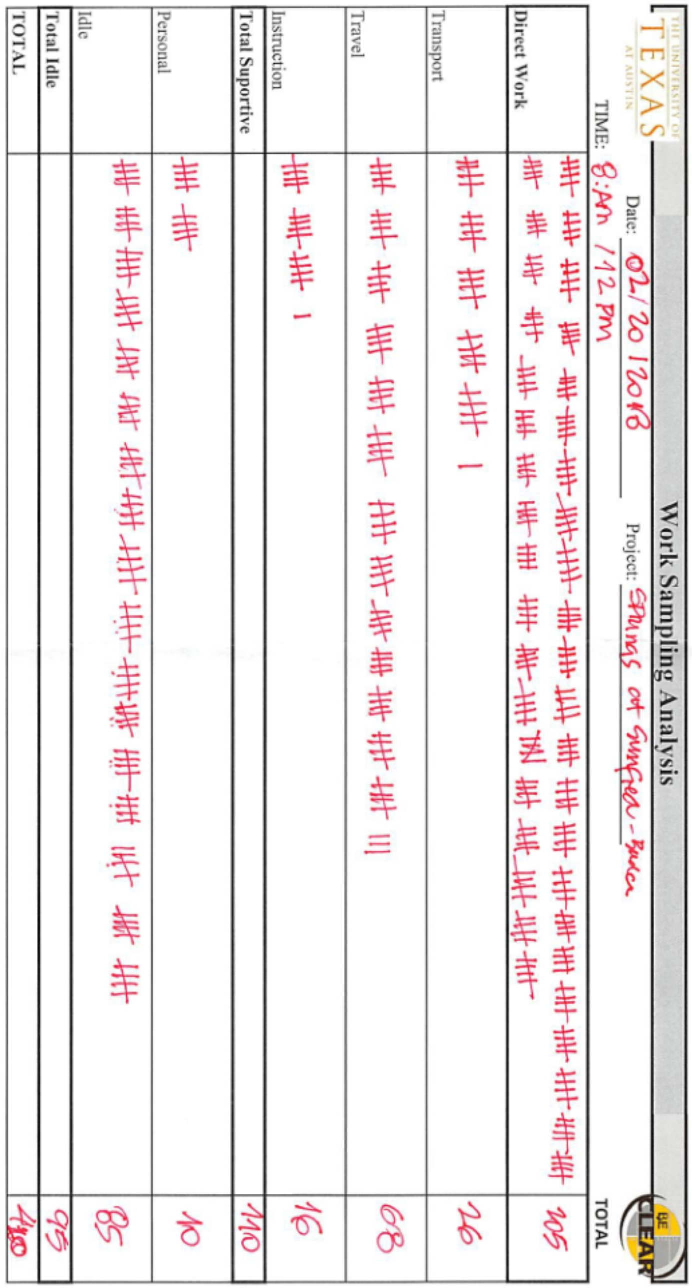
1. Work Sampling Analysis in Lean projects: This thesis uses Work Sampling outcomes from research conducted by Gong et al. (2010) to represent the industry average so that a comparison with the CFMx projects could be performed. However, Gong et al. (2010) analyzed data until 2008, and no Lean strategies were applied on these projects. In order to have a more

realistic comparison between the CFMx and the construction industry, it is fully recommended to perform Work Sampling Analysis on Lean projects.

2. Construction Flow Index in the CFMx: Sacks et al. (2017) developed the CFI (Construction Flow Index), which is a new methodology that measures the quality of flow in construction projects. This thesis uses the approach of Work Sampling to analyze the flow efficiency in CFMx projects. In further research, the CFI methodology from Sacks et al. (2017) can be applied in different CFMx projects and compared with the Work Sampling outcomes, so that two distinct systems of flow measurement can validate the results.
3. Work Sampling study on other two categories: This research divides the Work Sampling into main three categories, which are: productive work, supportive work and idle. This thesis focused more on the influence of the CFMx on the direct work ratio. Further research can analyze the impact of the CFMx on the other two categories of the Work Sampling, how the technique can minimize even more the supportive work and idle time.

Appendices

APPENDIX A – WORK SAMPLING DATA


THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

TIME: 8:AM / 12 PM   Date: 02/20/2018   Project: Springs at Gunfield-Brucea

Category	TOTAL
Direct Work	205
Transport	26
Travel	68
Instruction	16
Total Suportive	110
Personal	10
Idle	85
Total Idle	95
TOTAL	410

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

Date: 03/06/2018 Project: Springs at Sunfield, Buda TX

TIME: 8Am – 12PM

		TOTAL
Direct Work		215
Transport		34
Travel		50
Instruction		12
Total Suportive		96
Personal		18
Idle		79
Total Idle		97
TOTAL		408

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

BE CLEAR

Date: 03/20/2018 Project: Springs at Sunfield-Buda Tx

TIME: 8 Am-12 Pm

		TOTAL
Direct Work		201
Transport		37
Travel		50
Instruction		25
Total Suportive		112
Personal		10
Idle		71
Total Idle		81
TOTAL		394

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

Date: 04/03/2018 Project: Springs at Sunfield, Buda

TIME: 2PM - 5PM

		TOTAL
Direct Work		223
Transport		54
Travel		46
Instruction		10
Total Suportive		110
Personal		13
Idle		80
Total Idle		93
TOTAL		426

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

Date: 04/17/2018 Project: Rehab hospital, Round Rock, TX

TIME:		82 TOTAL
Direct Work		205
Transport		41
Travel		50
Instruction		15
Total Suportive		106
Personal		8
Idle		100
Total Idle		108
TOTAL		

THE UNIVERSITY OF TEXAS AT AUSTIN

BE CLEAR

Work Sampling Analysis

Date: 04/23/2018 Project: Rehab hospital, Newark

TIME: 2PM–5PM

		TOTAL
Direct Work		199
Transport		40
Travel		55
Instruction		25
Total Suportive		120
Personal		15
Idle		80
Total Idle		95
TOTAL		415

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

Date: 04/30/2018 Project: Rehab Hospital, Round Rock TX

TIME: 1PM–4PM

		TOTAL
Direct Work		205
Transport		41
Travel		46
Instruction		8
Total Suportive		95
Personal		7
Idle		99
Total Idle		106
TOTAL		406

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

BE CLEAR

Date: 04/17/2018 Project: Idea School, Pflugerville, TX

TIME: 1PM – 4PM

		TOTAL
Direct Work		190
Transport		52
Travel		45
Instruction		10
Total Suportive		107
Personal		13
Idle		100
Total Idle		113
TOTAL		410

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

BE CLEAR

Date: 04/23/2018 Project: Idea School, Pflugerville, TX

TIME: 6 AM – 12 AM 22

		TOTAL
Direct Work		198
Transport		66
Travel		56
Instruction		13
Total Suportive		135
Personal		9
Idle		78
Total Idle		87
TOTAL		420

THE UNIVERSITY OF TEXAS AT AUSTIN

Work Sampling Analysis

BE CLEAR

Date: 04/30/2018 Project: IDEA School, Pflugerville, TX

TIME: 9AM–11:30AM

		TOTAL
Direct Work		199
Transport		46
Travel		51
Instruction		11
Total Suportive		108
Personal		6
Idle		82
Total Idle		88
TOTAL		395

APPENDIX B – QUESTIONNAIRE AND INTERVIEWS

Project Managers Questionnaire – PM 1

1. General Information
   1.1. Type of Project: *Multifamily Apartments*

   1.2. What type of work are you performing in this project?

   Work as scheduler for Lott Brothers Construction Company

2. Clear Flow Matrix Evaluation

   2.1. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?

The main differences are how easily communicates, what the scheduling is, where the people need to be in, how far ahead or behind are you on the schedule. Another good thing in the Matrix is the binary instead percentage based, which is "done and not done".
I worked mainly with Microsoft project and sometimes with primavera.

   2.2. How has the Clear Flow Matrix improved your company?

.

At personnel level, with the matrix I have a lot less work to create and manage schedule. The workload decreased significantly for scheduling. For instance, I have a 50 millions dollars project with more 150 000 sq/ft, five different building groups, four-story, park garage, etc. It is a very complicated project. If I would have created a CPM schedule project for it, it probably would take me two solid weeks, and I took me less than a day to schedule using the Matrix. So, the CFMx decreases the work to create the schedule and also to update it.

   2.3. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Yes, certainly.

2.4. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes. One of its advantages is the good communication of the schedule. CFMx represents very clear the whole schedule.
A CPM schedule using the MS Project to me is clear, because that was part of my job to create scheduling. But for the Subs, that are building the project, they usually do not understand. What I watched to happen was, during the subcontractor meeting everybody used to say , "yes we understand", but after the meeting it was like everybody has thrown the schedule in the trash and they do whatever they wanted. The CFMx is easier visually to understand.

2.5. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?

I have been working here for many years and my experience was that once the Superintendent or Foremen start to use they really enjoy versus the traditional schedule. The Subs can actually use as a tool instead just to have a piece of paper.

2.6. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

I have seen some people saying that the CFMx does not represent every little things that need to be happen in job sites. But I think it does provide enough detail to be a good scheduling tool. However, it is not the only tool that you need to manage your project, but I think for schedule standpoint yes. You still have to have the weekly meetings in your handoffs process to talk about all the little details. We do not spell out every single activity on the CFMx. That is the whole point, once you put too much detail that in, then it becomes unclear. It gets confusing to use as tool. So, you need the combination between CFMx and the weekly meetings to manage projects. As a scheduling tool, it provides enough detail.

2.7. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. I do not see any problem, but I think it can be improved. For instance, maybe creating a app or something similar, that you can put in your phone and you can

see while you walk in the job sites instead using piece of paper. In other words, digitalize the use of the CFMx.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

I can say in general. Lott Brothers is my fourth G.C company that I work for, and for a schedule standpoint we do significantly productivity improvements..

2.9. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?

Yes. Because at any time the CFMx provides an accurate schedule. It helps the Subs to put their resources in that project and coordinate with other projects. For example in this project (he showed me a Matrix), using the CFMx I can look ahead a year from now and know exactly where each trade contractors have to be working and the amount of work that they will have. It helps a lot to coordinate resources. There is no way to pull out this information in traditional scheduling tool.

2.10. Does the Clear Flow Matrix help reduce the cost of projects?

I have seen different opinions from different subs, for example, many subs want perform their job in a faster pace than the CFMx. They usually think "If I work as faster as I can, I will reduce my overhead, which I will reduce my cost". That is true. It may reduce in some cases. Working at the pace of the CFMx, in some cases we might be forcing certain trades to increase their overhead, increasing their cost. But, thinking about the relationship between quality of work and the speed of work, the quality goes down if you perform your job too fast. You won´t be able to control the quality, then you will have a big punch list, more rework, etc, So how do you calculate if you saved your money or not? It is hard to keep track of all that.
My opinion is that you should save money because it is more planned, it is more organized, it is more efficient.

Project Managers Questionnaire – PM 2

1. General Information
   1.1. Type of Project:
   Hospital
   1.2. What type of work are you performing in this project?
   Dry Wall

2. Clear Flow Matrix Evaluation

   2.1. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?
   The matrix is more exact. Bar chart has a broader look.

   2.2. How has the Clear Flow Matrix improved your company?

   CFM has not improved the company, but has improved the job site schedule.

   2.3. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?
   Yes, It is.

   2.4. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?
   Yes, it is better than CPM Bar Charts and it is more understandable.

   2.5. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?
   The key point is that they know exactly where they is supposed to be. CFM shows exactly the location of each trade in jobsites.

2.6. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.7. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. However, the only problem is that if you have one sub that is not following the Matrix, it affects the other trades behind it..

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

Yes, absolutely.

2.9. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?

Yes, special material. Because with the matrix, for instance, you know exactly how much square foot you have to do in next week and you know how much square foot you have to do in the week after.
Using the Matrix , the areas have about the same size. On the other hand, the areas of CPM are not homogeneous. They are big, small, big. As the CFM breaks the areas with almost the same size, you will have the crew size, material, resources also pretty much the same for the whole project . On the other hand, using the CPM you might have 30 guys this week and 10 guys in the week after. With the matrix you can maintain the same crew size for the whole project.

Project Managers Questionnaire - PM 3

1. General Information

1.1. Type of Project:

Hospital

1.2. What type of work are you performing in this project?

Electrician

2. Clear Flow Matrix Evaluation

2.1. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?

The Matrix is more specific than CPM Bar-Chart. CFM shows not only the durations of a certain piece of work, but each person´s duration of that piece of work.

2.2. How has the Clear Flow Matrix improved your company?

CFM has definitely improved the company, because it has changed the way that we planed and how we started the project. Because we can see the locations for the whole project and help us to coordinate crew or resource in general.

2.3. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Yes, It is., so long everybody is on board, because if there is one or two people that do not keep up to date on their part of the matrix, then it does not mean anything. It needs everyone correct input to be effective.

2.4. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, you can see everything.
Depends on what you are looking for. For instance, if are looking at what section of the project we enter, I would say Bar Chart. But if you want to get more detail, like, where are you in the project now, or where you were yesterday, where are you going to be tomorrow , I would say the Clear Flow Matrix. Bar Chart makes a better glance tool and CFM is much better to follow and to manage the projects;

2.5. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?

Very negative in the beginning, but once they understood how it works, they liked a lot.

2.6. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.7. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. No I do not have any problem to work with the clear flow matrix.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

Yes. It would be very hard to measure. We avoided so many common problems and common scheduling mishaps, because the CFM requires everybody to schedule together.

2.9. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?

Yes. One of the main strong thing of the clear flow matrix is the crew size. Because the matrix shows exactly the amount of work for the following weeks.
In regard to the coordination between two projects, it helps not much.

Project Managers Questionnaire – PM 4

1. General Information

1.1. Type of Project:

Multifamily Apartments

1.2. What type of work are you performing in this project?

Swimming pool construction

2. Clear Flow Matrix Evaluation

2.1. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?

Honestly, I'm not a fan of the CPM Bar chart. It accurately displays the schedule but is scattered around. I much prefer the Clear Flow Matrix because everything is completed in waves and is easier to read quickly.

2.2. How has the Clear Flow Matrix improved your company?

It has minimized the amount of phone calls or emails needed to coordinate start dates and/or turnover dates.

2.3. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Yes, I picked up the matrix fairly quickly. And for a superintendent it really helps us schedule out our crews in an organized way. Less chance for double booking and wasted trips.

2.4. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?
The Clear flow is much easier to understand and grasp

2.5. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?

We have asked other General Contractors to adopt this tool and use it on their jobs.

2.6. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes, for large construction sites it's a must

2.7. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes, it's a solid program

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

Yes, less chaos amongst other trades. The matrix tells everyone universally what needs to be done and when it needs to be complete. Keeps guys honest and prevents a lot of finger pointing.

2.9. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?
I don't use the matrix to justify amount of manpower. If anything the deadline tools with the matrix help me adjust accordingly.

Project Managers Questionnaire – PM 5

1. General Information

1.1. Type of project: *Hospital*

1.2. What type of work are you performing in this project?
Mechanical

2. Clear Flow Matrix Evaluation

2.1. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?

-I have worked with most of the different scheduling philosophies and tools out there. Most end up tracking the work on a monthly basis in more of an as built condition, but CFM manages the work on a daily-weekly basis and requires instant accountability and action.

2.2. How has the Clear Flow Matrix improved your company?

-As a subcontractor it is more project related than company related and we have had success as relates to CFM scheduling on LBCC projects.

2.3. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?

-Yes and it is a good tool. Keys to set up are breaking down the project such that each area can be built in the CFM cycle, subcontractors have to buy in and be ready to go to work, and it has to be managed and updated on a weekly basis.

2.4. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

-*I have been part of a dozen or more projects with LBCC using the scheduling method and experienced its success over and over.*

2.5. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?

-*When they are new to it there is generally a sense of resistance and disbelief because they have been promised for decades that the schedule is going to work and be successful on whichever project they were assigned at the time. Unfortunately and most often, that is not the case.*

2.6. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

-I do and think it flies at just the right height, enough detail but keeps out of the weeds.

2.7. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

-*It is my preference…*

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

-*I would say more the productivity and workflow are maintained and incrementally managed. We have worked on projects that used more traditional scheduling tools and when the contracting team maintains and progresses the activities in the schedule the productivity is generally complimentary*.

2.9. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?

-*CFM breaks apart the project is like size areas, which allows for a bell curve of manpower. In that regard it is a resource coordination dream and the alternative is ramping up and down quickly, which generally suggests there was a flaw in the plan or schedule*.

2.10. Does the Clear Flow Matrix help reduce the cost of the project?

-*I would say it manages the cost and does not let the large overruns that many projects experience. It has been my experience that when a project runs on schedule that the costs are in line and this method of scheduling that LBCC uses is an excellent tool in that regard*.

Project Managers Questionnaire – PM 6

1. General Information

1.1. Type of project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?
Turnkey Doors and trim

2. Clear Flow Matrix Evaluation

2.1. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?

The hardest part for our scope of work is nailing down the exact date that material needs to be on the project. This chart helps us understand the overall length and relative scope for us and what trades are involved before and after, but we still have to work with superintendent to make sure we nail down correct dates.

2.2. How has the Clear Flow Matrix improved your company?

It helps us understand length and time of work to be performed and overall schedule.

2.3. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?

I understand the basics. As a subcontractor I would not use this tool, but I like working with a company that is organized and has the flow scheduled for each trade.

2.4. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Both can be helpful once you understand what the chart is representing. Once I spent a little time looking at the clear flow matrix it does present information in a way that is easy to understand.

2.5. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?

I have not specifically discussed this.

2.6. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

I think it helps with the overall schedule. The day to day changes so quickly that I don't think all communication could exclusively be on this chart.

2.7. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

I don't have a problem with it, but I also don't necessarily need it. As long as communication with the superintendent is presented clearly, we are able to do our work efficiently.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

It helps that the people running the project are organized. I don't know that it directly relates to the clear flow matrix.

2.9. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?

It does help us understand what the expectation is for the project.

Project Managers Questionnaire – PM 7

1. General Information

1.1. Type of project: *Hospital*

1.2. What type of work are you performing in this project?
Mechanical and Plumbing

2. Clear Flow Matrix Evaluation

a. You may know that for this project a new technique has been used to control the schedule, the Clear Flow Matrix. You may have worked before with other scheduling tools, for instance, CPM-Bar Charts. Do you see differences between these two methods? If yes, what are the main differences?

This Method provides clear unchanging path.

b. How has the Clear Flow Matrix improved your company?

Advanced planning and accountability.

c. Do you know how the Clear Flow Matrix works? Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Great tool for all trades.

d. Have you seen the Clear Flow Matrix? Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

The CFMx is very clear in its presentation and much easier to understand.

e. What are the feedbacks from your Superintendents and Foremen about the Clear Flow Matrix?

Great for planning and making everyone accountable to each other for the goal of the entire project.

f. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes

g. Would you like to work again with Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes, No problem.

h. Have you seen any productivity improvement using the Clear Flow Matrix in this project in comparison to other projects that the Clear Flow Matrix was not used?

Yes

i. Does the Clear Flow Matrix help the coordination of resources (crew size, equipment and material) within this project and also within other projects?

Absolutely.

Foreman Superintendent Questionnaire – Foreman 01

1. General Information

    1.1. Type of Project: *Multifamily Apartments*

    1.2. What type of work are you performing in this project?

    HVAC

    1.3. How long have you been working in this job?
    From Start

    1.4. How many men are in your crew?
    12

2. Clear Flow Matrix Evaluation

    2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

    Yes. It is good.

    2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

    I have not seen any other type of scheduling tool. In other projects, the GCs have given me only the finish dates, but I have not had contact with scheduling tool before. Here the GC (Lott Brothers) presents us the whole scheduling with all trades and you can see beforehand the upcoming tasks. I like a lot the matrix because you have an overall presentation of the activities including all trades involved in the project.

    2.3. Does Clear Flow Matrix have a good visual presentation? Is the Matrix an intuitive tool? In comparison to the previous methods used in other projects, which one is easier to understand?

Yes, the Matrix has a good visual presentation.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix?

Yes.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. Enough time.

2.7. Does a “one-week-duration” (to manage the schedule of a project) work for you?

Yes

2.8. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

I have not had problem with conflict area and no problem for waiting.

2.9. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes. I could distribute my crew in different buildings at the same time improving the productivity.

2.10. Is the sequence of work logical in the Clear Flow Matrix?

Yes, good.

2.11. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

Yes.

2.12. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No. I know everyday the location of my crew. In other projects, I have had problem of not knowing the location.

2.13. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Yes, I have to work overtime here. In other projects I have had to work more overtime than here.

2.14. Does the Clear Flow Matrix help you with the crew size? How?

Yes. Because, the matrix gives me previously the amount of work that I am going to have in the following weeks. I can manage better my crew.

2.15. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

Yes. In this project. I do not have other projects at the moment.

2.16. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

No.

2.17. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions? Has the Clear Flow Matrix helped with changes in comparison to other scheduling tools?

2.18. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Sometimes I have had rework. Because either someone broke any piece or the location of one piece had to be changed. However, I have had less rework in this project than the others.

Foreman Superintendent Questionnaire – Foremen 2

1. General Information

1.1. Type of project: *Multifamily apartments*

1.2. What type of work are you performing in this project?
Dry Wall

1.3. How long have you been working in this job?

About one month and half

1.4. How many men are in your crew?

15 to 20

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. Using the CFMx everybody works at the same pace and therefore it helps keep the schedule on time.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

No, I have not worked before

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

No, Because I do not need this tool to perform my job. Only the start and finishes dates is enough,

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No. Sometimes the location is not ready and then I have to wait.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes., I have seen productivity improvements

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

No, remained the same.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

No.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Remained.

Foreman Superintendent Questionnaire – Foremen 3

1. General Information

1.1. Type of project: *Multifamily apartments*

1.2. What type of work are you performing in this project

Framing

1.3. How long have you been working in this job?

3 Weeks

1.4. How many men are in your crew?

45

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Yes. It keeps the project going. The matrix has helped to keep the project on the schedule.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

I worked before with Bar-Chart. Like I said, I am just getting into the Matrix and until now I do not see much difference, but the matrix seems to work little better.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes. The matrix is easier. We can see what building and what date we have to be working. The matrix gives me also start and finish date. The scheduling using the matrix is more organized.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. I getting used with the Matrix, but I think it is a helpful tool.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period *of one week?*

Yes. One week is ok. It is fits good. The weekly meetings are also good for me.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Not much. No.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes, because the matrix helps to complete the work on time.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

No overtime in this project. In comparison to other projects here we have less overtime.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes. Because, since we have to finish a certain area or a certain floor in specific time, we have to put more workers order to do that. It helps maintain a good crew.

2.13. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

Yes, but I only have this project at the moment.

2.14. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

No changes.

2.15. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions? Has the Clear Flow Matrix helped with changes in comparison to other scheduling tools?

2.16. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

We have often rework here. In comparison to other projects the rework is the same.

Foreman Superintendent Questionnaire – Foremen 4

1. General Information

    1.1. Subcontractor company name: *Multifamily Apartments*

    1.2. What type of work are you performing in this project?
    Framing

    1.3. How long have you been working in this job?
    2 months

    1.4. How many men are in your crew?
    60

2. Clear Flow Matrix Evaluation

    2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

    Yes. Because it gives you dates of everything. You have an overall view of whole project.

    2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

    In other projects I have not had contact with any other type of scheduling tool. GC has given me only the dates and the local to perform his job. However, in comparison to other projects, the matrix gives you an overview of the complete work and what work still needs to be done.

    2.3. Does Clear Flow Matrix have a good visual presentation? Is the Matrix an intuitive tool? In comparison to the previous methods used in other projects, which one is easier to understand?

    Yes. Good.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes, because you can see every dates of the project easily.

2.5. Would you like to work again with the Clear Flow Matrix?

Yes.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period *of one week?*

Yes

2.7. Does a "one-week-duration" (to manage the schedule of a project) work for you?

Yes

2.8. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No, never.

2.9. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes, it has improved in comparison to other projects.

2.10. Is the sequence of work logical in the Clear Flow Matrix?

Yes.

2.11. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No, the same.

2.12. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.13. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Sometimes. In comparison to other projects the overtime is higher in this project, because you have to be always on time.

2.14. Does the Clear Flow Matrix help you with the crew size? How?

Yes. Because using the Matrix you can forecast how much work you are going to have in the next days.

2.15. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

He only has this project at the moment.

2.16. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

No changes.

2.17. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions? Has the Clear Flow Matrix helped with changes in comparison to other scheduling tools?

2.18. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Decreased.

Foreman Superintendent Questionnaire – Foreman 5

1. General Information

1.1. Type of project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?

Light weigh concrete - Gypcrete

1.3. How long have you been working in this job?

30 days

1.4. How many men are in your crew?

7

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes, it is good. The matrix has become my job easier, because, every time that I come here to perform my job, everything is done for me and I can start to do my work. The other projects are not like that.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Yes, Bar-Chart.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, but I prefer the presentation of Bar-Chart which is easier to understand, because I am more familiar with Bar-Chart

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

I prefer Bar-Chart. I do not have any problem with the Matrix

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Working together: Two or three times.
Stop work: No. In other project, it has happened.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes, due to the supervision from GC.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No. In other projects I do not have also problems with this. Because, usually we do the whole building and no in "piece" work (areas).

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Yes, but here I have worked less overtime than in the other projects, because here it is more organized.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

No. It does not matter if it is Bar-Chart or Matrix to manage my crew size.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Remained the same.

Foreman Superintendent Questionnaire – Foremen 6

1. General Information

1.1. Subcontractor company name: *Multifamily Apartments*

1.2. What type of work are you performing in this project?
Fire Alarm/Low Voltage

1.3. How long have you been working in this job?
18 days

1.4. How many men are in your crew?
10

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. The matrix is better for me.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

I have worked before with Bar Chart. Matrix is easier to follow. The main difference in comparison to Bar-Chart is that the matrix compresses the whole schedule in one page.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, the Matrix has a good visual presentation. Matrix is easier to understand. Bar Chart is less organized and easier to be out of the sequence.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. I do not have any problem with the Matrix.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. I need actually less than week. But, the weekly meetings is good my work.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No. No.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

No, the same.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No, because I have small scope in the project.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Until now I have not any overtime. I cannot compare because I am in the beginning of the project here.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

No, because I have small crew, only 3 men.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

No rework.

Foreman Superintendent Questionnaire – Foreman 7

1. General Information

1.1. Type of Project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?
Painting

1.3. How long have you been working in this job?

I started here 2 weeks ago

1.4. How many men are in your crew?

6

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes , (he could not answer how)

2.2. You have worked before with other types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

CPM Bar Chart,, the main difference is the representation, that the CFM gives you the schedule in only one page.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, CFMx is easier.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes, No problem.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No, never.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

No

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?
No

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Not often. Remained the same.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

I cannot say because, I have just started to work here.

Foreman Superintendent Questionnaire – Foreman 8

1. General Information

1.1. Type of project: *Multifamily apartments*

1.2. What type of work are you performing in this project?
Plumbing

1.3. How long have you been working in this job?

Since September 11th

1.4. How many men are in your crew?

12

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. Makes the job to go faster. Less time involved.

2.2. You have worked before with other types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

CPM Bar Chart, but I was not too much involved. The matrix gives more detail about the schedule and is more sophisticated.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, CFMx is easier.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes, No problem.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Not often. Yes , not often.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes., I have seen productivity improvement.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Yes, Less overtime.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

It does not help me with the crew size.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Decreased.

Foreman Superintendent Questionnaire – Foreman 9

1. General Information

1.1. Type of Project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?

Installing Shingles Roofing

1.3. How long have you been working in this job?
December 2017

1.4. How many men are in your crew?
8 people

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

It is, but is not perfect. It gives you an idea of where you should be working. It is not perfect because of the weather conditions. The matrix does not take into account the weather days, it means the dates are not changed due to weather conditions.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

He has not dealt before with any type of scheduling tool, just regular meetings. GCs usually give him the date and location that his crew has to be working. He has not had this kind of interaction with scheduling in other projects.

2.3. Does Clear Flow Matrix have a good visual presentation? Is the Matrix an intuitive tool? In comparison to the previous methods used in other projects, which one is easier to understand?

It is easy to understand. As he has not seen any other type of scheduling tool before, he could not answer the last question.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix?

Yes.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

It fits good.

2.7. Does a “one-week-duration” (to manage the schedule of a project) work for you?

Yes, very good.

2.8. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No. No. We are only crew on the roof.

2.9. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes. It goes pretty quick. Productivity has increased, it flows well.

2.10. Is the sequence of work logical in the Clear Flow Matrix?

Yes.

2.11. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.12. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No. We always know where is supposed to be. In other projects we also always know.

2.13. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

No overtime. In comparison to other projects the overtime was higher than here.

2.14. Does the Clear Flow Matrix help you with the crew size? How?

No. We have always the same people working on the projects.

2.15. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

Yes. It has helped me.

2.16. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

No.

2.17. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions? Has the Clear Flow Matrix helped with changes in comparison to other scheduling tools?

2.18. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

The rework here is lower than other projects. However, we have always to go back to every building because something is "bad" (broken). For example, we are working on area number 5 and we have to go back to area number 2 because HVAC workers did penetration through the roof, so we have to go back and fix it.

Foreman Superintendent Questionnaire – Foreman 10

1. General Information

1.1. Type of Project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?

Work as scheduling / Superintendent

1.3. How long have you been working in this job?

About ten years / In this project 4 months

1.4. How many men are in your crew?

2 people

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes, it is. CFMx helps you to quickly identify the status of the job. It helps the company as a communication tool. You can see where you are very quickly. It helps also to focus on bottleneck or the areas that you need to do before you can move to the next task. The only problem that I see is that the matrix does not represent all the information you need to manage the project. There are details behind the matrix you have to know. For instance, if you look at the painting activity, you have to know if the submittals are approved, the paint has been ordered, are the paint colors approved. It is a generalized representation, it is not very detailed.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

CPM schedule, *if you compared with CPM schedule, I think you have little bit more detail using CPM than the Matrix. However, the CPM you cannot identify the bottlenecks.*

The whole point of a scheduling tool is to identify where the work is and are we there or not? The CFMx does the way better job of making an assessment of where we currently are.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, absolutely. It is very intuitive. However, we have to spend some time to teach subcontractors what throughput time is, what takt time means, etc. But it happens with any other scheduling tool. We have to make an effort to teach subcontractors how the technique works. So, far as presentation, CFMx is better. The reason that CFMx is such a big deal is because a lot of subcontractors can easily understand. This is not happen with CPM, which many people in the construction industry cannot grasp the method. They do not understand the duration of the activity, where the CFMx from presentation standpoint identifies very quickly.
Even the CFMx is intuitive, we have here to make an effort to breakdown and explain it.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

I think that CFM is generic and not much detailed.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. No I do not have any problem. I think it is a very useful tool. A great tool and very effective.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. However, the way the matrix is built for this job is not the most efficient way. For instance, building inspector does not want walk one floor. He wants to inspect the entire building. That is the problem with the CFMx in this particular job is I do not feel that is built as the most efficiency way. I do not think from the actual reality of the way that the inspector would like to be done is not the CFMx way. You have more smaller handoffs instead one big handoffs. The subcontractors do not like to do floor by floor like in this particular project. They prefer to break the building in half, working top and bottom simultaneously. I think it would be more efficient if the areas were defined by half

of the building top and bottom floor exactly the same thing. This is valid only for the interior matrix and not for vertical matrix.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No, I do not. Because I breakdown the floors in smaller areas and my takt time is daily. I show them every day where they are supposed to be working.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes, it has improved, because everybody understands where the works is behind and where you supposed to be working.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

Yes. But, in this particular job no. As I said before, it is vey inefficient. This project should not be broke down by floor, but rather half of the building with two floors simultaneously.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No. Everybody understands where they should be. CFMx shows very clear where they supposed to be.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

It is up to subcontractor trades and not to the CFMx. For example, some trades try to use minimum manpower and they end up working longer hours. So, this is their fault. I do not feel that CFMx helps in reducing the overtime in projects. The CFMx has anything to do with this.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes, it should help you, because every takt time starting on a Monday, you should know you have five working days to complete. So, you should know that you need X guys to be able to perform the job in five days.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Rework has decreased tremendously. It has to do with the hand off process, that is weekly basis. The hand off is meant to be where we as superintendents verify the work whether it is complete.

Foreman Superintendent Questionnaire – Foreman 11

1. General Information

1.1. Type of project: *School*

1.2. What type of work are you performing in this project?

Masonry

1.3. How long have you been working in this job?

About one month and half

1.4. How many men are in your crew?

15 to 20

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. It does you more productive. The other trades have the same schedule and the same set up, It pushes you. It makes also more area ready. When you have more areas ready you are more productive.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Yes, Pull Planning (Last Planner). Not really, basic the same thing. I think like pull planning.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, it has a good visual presentation. But for me the pull planning is easier to understand because I am more used to work with.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. No I do not have any problem.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

No. One week is to short to me to perform this area. I need two or three weeks.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Yes, Often
Yes.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes. In comparison to Pull Planning the productivity is the same.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Yes, very little. It is in the average with other projects.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes, because you know what you have to do in certain period of time and you can adjust the crew size.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Remained the same.

Foreman Superintendent Questionnaire – Foreman 12

1. General Information

1.1. Type of Project: *School*

1.2. What type of work are you performing in this project?

Painting

1.3. How long have you been working in this job?

More than two months

1.4. How many men are in your crew?

4

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes, (but he could not explain why).

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Yes, CPM Bar-Chart. He prefers CFM, because it is easy to understand. (He could not explain too much why. He has not had much contact with other scheduling technique)

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, it does. The matrix is easier to understand.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes, it does.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes I could work again with the clear flow matrix and I do not have any problem with it.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. Yes.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No, I have not had conflict with other trades. No, I have not had to move to another place or wait.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

It has improved my productivity.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Not really. Here it has less overtime.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes, because you know exactly in that day the amount of work that you will have, You can better forecast the amount of work for the following weeks.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Decrease the rework.

Foreman Superintendent Questionnaire – Foreman 13

1. General Information

    1. Type of project: *School*

    2. What type of work are you performing in this project?

Steel Framing and Dry Wall

    3. How long have you been working in this job?

Nine months

    4. How many men are in your crew?

About 15

2. Clear Flow Matrix Evaluation

    2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes, it is. Improve the way that you can organize things. It improves also the communication between trades and contractor (All the schedule trades are represented in one single page). The Matrix also accelerates the process to build better and right. The matrix avoids miscommunication between trades and GC, because everybody is involved.

    2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Yes, Pull Plan (Last Planner) and CPM Bar-Chart. The main difference for me it that Pull Plan is more detailed and the Clear Flow Matrix is more generic. But both are good to work with. However the CFMx is easier to understand.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes. CFM is easier to understand.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

I think that CFM is generic and not much detailed.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

Yes. No I do not have any problem.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes, I have the perfect amount of work to perform my job in one week.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Yes, yes. It happens every single job.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

Yes, my productivity has improved using the clear flow matrix.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

Yes, because you won´t get in the area where is not ready for you.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No. I know every day where my crew is supposed to be working.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Sometimes. But using the Clear Flow Matrix the overtime has decreased.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes, definitely. Because the schedule says to you the area, the amount of work and the time that you have to perform the job You can determine how many people it is going to be needed.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Sometimes happen here. It happens in all projects. Remained the same.

Foreman Superintendent Questionnaire – Foreman 14

1. General Information

1.1. Subcontractor company name: *Hospital*

1.2. What type of work are you performing in this project?

Dry Wall

1.3. How long have you been working in this job?

About two Months

1.4. How many men are in your crew?

18

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. (he could not explain why it has improved).

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Some projects the scheduling information was verbally (Ex. This week you need to do this and so on). It means that I have not had contact with scheduling types. Some projects they used CPM Bar Charts. I prefer the Matrix in comparison to other scheduling tools. It is a good system to push everybody.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes. In comparison to BarChart, matrix is better. It is easier to understand.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes, there is a lot information in the matrix.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

.Yes. No I do not have any problem.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. This is perfect for one week..

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No. I do not have conflict area. No. In other projects (without the CFM) I used to have conflict areas.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

It is more productive with the CFM.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No. The same

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Yes. Here the overtime is the same with other projects.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Remained the same. When I have rework, the CFM does not take into account the time spent on rework .

Foreman Superintendent Questionnaire – Foreman 15

1. General Information

1.1. Type of Project: *Hospital*

1.2. What type of work are you performing in this project?

Exterior Glass and Glazing

1.3. How long have you been working in this job?

One week

1.4. How many men are in your crew?

6

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. Basically it is a daily update. The CFMx gives you very quickly the status of the project in regarding to schedule. It is also very easy to identify the locations that you need to be.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Last Planner System. The main difference to me is that the CFMx is more visual than the other, and everybody can see the whole schedule improving the communication among the trades. I can better follow the projects with the CFMx.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes. In comparison to Last Planner, the CFMx is easier to understand.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes. For me it has detail enough to be a good scheduling tool .

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

.Yes. No I do not have any problem.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. As long the weather permits you to work, it should be ok.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

No. Never.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

I cannot answer now, because I have just started to work in this project.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

I cannot answer now, because I have just started to work in this project.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

I cannot answer now, because I have just started to work in this project.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

I cannot answer now, because I have just started to work in this project.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

Yes. maybe. I cannot answer precisely now, because I have just started to work in this project.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

I cannot answer now, because I have just started to work in this project.

Foreman Superintendent Questionnaire – Project 16

1. General Information

1.1. Type of Project: *Hospital*

1.2. What type of work are you performing in this project?

Plumbing

1.3. How long have you been working in this job?

About 2 weeks

1.4. How many men are in your crew?

7

2. Clear Flow Matrix Evaluation

2.1. Do you think that the Clear Flow Matrix is a good construction scheduling tool? How has the Clear Flow Matrix improved your company?

Yes. Because CFMx provides a better planning and the projects becomes more organized. I know every week the amount of work that I will have and the location. It helps me to coordinate my crew.

2.2. You have worked before with others types of scheduling tool. Can you give me an example? Do you see differences between the Clear Flow Matrix and that one? If yes, what are the main differences?

Yes. CPM Bar-Charts. Both methods give to me start and finishes dates, which are one of the most important information that I need. However, the CFMx is much easier to understand.

2.3. Does Clear Flow Matrix have a good visual presentation? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes. As I said, the CFMx is easier to understand. For example, I can see in one single page the whole schedule for this project.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with the Clear Flow Matrix? Do you have any problem to work with the Clear Flow Matrix?

.Yes., sure. But the problem that I am having here is that the pace of the CFMx is faster than usual.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

No, not enough time. I have much work to complete in one week. The areas could be smaller so that I could do it in five working days.

2.7. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Yes, I have sometimes, but not often, to wait another trade finish their job so that I could enter in that area and perform mine.

2.8. Have you seen any productivity improvement using the Clear Flow Matrix in comparison to another type of scheduling tool used before?

CFMx is more productive than CPM. Because, as I sais, it makes the project more organized, improving the productivity.

2.9. Have you seen any decrease of unnecessary crew movement using the Clear Flow Matrix?

No. The same.

2.10. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No. Never. I always know where they is supposed to be.

2.11. Do you have often workers work overtime on this project? In comparison to other projects, which the Clear Flow Matrix was not used, has the overtime work decreased?

Yes. Here the overtime is the same.

2.12. Does the Clear Flow Matrix help you with the crew size? How?

No. To me this tool does not help me with crew size.

2.13. Using the Clear Flow Matrix on this project, has rework increased, decreased or remained the same in comparison to other projects in which the Clear Flow Matrix was not used?

Increased. I think it is because we have to work faster than usual and it makes to increase the rework.

Foreman Superintendent Questionnaire – Foreman 17

1. General Information

1.1. Project Type: *Multifamily Apartments*

1.2. type of work are you performing in this project?

Electrical

1.3. How long have you been working in this job?

Since November 2017

1.4. How many men are in your crew?
10

2. Clear Flow Matrix Evaluation

2.1. You have worked on this project with two different methods of scheduling, CPM-Bar Charts and the Clear Flow Matrix. Do you see differences between these two methods? If yes, what are the main differences?

GENERAL COMMENTS: The problem of using Matrix is that, for example, if the painter is behind, it pulls me also behind. It backs whole trades up, causing chain reaction. Nobody can work in one area other than that trade (showed in the Matrix).

I have my own schedule, and the matrix scheduling does not match with my schedule (sometimes the matrix put things on there that is not even time yet, like why are you worrying by now?) It tights up my time.

Not really difference, because what he needs is the start date and finish date. But Bar chart is easier.

I like more the Bar Chart, because it shows the start date and finish date and you do not need much detail. He thinks the "big Matrix" ok, because shows the start and finish date and where you suppose to be working, however I do not like the "zones" of the Matrix , because it tries to "Micromanage you". This "section" used in the matrix uses more time to perform the job. It is easier and save more time if you go in and just do the whole building in one time.

2.2. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

No, because they try to micromanage. If you know how to do something you just need the start and finish date.

Change his idea: Clear flow matrix is a good schedule tool. The problem of using Matrix is that, for example, if the painters is behind, it pulls me also behind. It backs whole trades up, causing chain reaction. .

In general, I like because gives you the date and the local that you have to work;

2.3. Does Clear Flow Matrix have a good visual presentation? Is the Matrix an intuitive tool? In comparison to CPM – Bar Charts, which one is easier to understand?

Too busy for me (section, zones). I do not like too much, because of "micromanage". They do in their way instead our way. "They tell us how to do it". ". Matrix changes the way that you are used to work. I know the best and cheapest way to do my job, but with the matrix I cannot perform in that manner. I like more the Bar chart because I need only the start and finish date.

Bar chart is easier to understand.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Too much. Because of the section. If left the section out it would be ok. Using the section, they tell me how to do my job.

2.5. Would you like to work again with Clear Flow Matrix?

Not really, but If I´ve got to, I would work.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes.

2.7. Does a “one-week-duration” (to manage the schedule of a project) work for you?

Yes.
All I need, is the start and finish date.
The section is not good, I could save one day and half If I do other way.
“I can save money using “Bar-Chart”

2.8. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Not much at all. Only twice, in building 11 and 12 (because of rework).

2.9. Have you seen any productivity improvement since the Clear Flow Matrix was introduced in this project?

No.

2.10. Is the sequence of work logical in the Clear Flow Matrix?

No, because they cut it up in sections. They try to micromanage. They tell me how to do it.

2.11. Have you seen any decrease of unnecessary (crew) movement since the implementation of the Clear Flow Matrix?

No.

2.12. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.13. Do you often have workers work overtime on this project? Has the overtime decreased since Clear Flow Matrix was initiated in this project?

Once. (He could not answer the second part of question because when he got in the project, the matrix had been introduced).

2.14. Does the Clear Flow Matrix help you with the crew size? How?

No. "they do not tell me how many guys should I have here". The only way to help me if they would have said me how many men hours is needed to perform this job, but they do not tell me. They give me only start dates.

2.15. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

Yes.

2.16. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

Only change my schedule, because painters were behind. We just found other things on the job to do. It has pulled me back (design changes he has not had).

2.17. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions to the schedule? Has the Clear Flow Matrix helped with changes in comparison to the previous scheduling method (CPM – Bar Charts)?

2.18. Since the Clear Flow Matrix was introduced on this project has the rework increased, decreased or remained the same?

Rework has nothing to do with the Matrix. It has to do with Foreman. Matrix is just a date scheduling tool.

Foreman Superintendent Questionnaire – Foreman 18

1. General Information

1.1. Type of Project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?

Plumbing

1.3. How long have you been working in this job?

2 years

1.4. How many men are in your crew?

3

2. Clear Flow Matrix Evaluation

2.1. You have worked on this project with two different methods of scheduling, CPM-Bar Charts and the Clear Flow Matrix. Do you see differences between these two methods? If yes, what are the main differences?

Not really much difference, but the Clear Flow Matrix is better. Because you know your flow of work.

The weather condition is a big problem in the matrix. If the weather is too cold, for instance, you cannot hit that date according to the matrix. If there weren´t weather problems, the matrix would be really good. I like the matrix, because it is pretty easy to understand.

2.2. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Yes

2.3. Does Clear Flow Matrix have a good visual presentation? Is the Matrix an intuitive tool? In comparison to CPM – Bar Charts, which one is easier to understand?

Yes, because you can easily see the finish date of the project. .The matrix is easier to understand than Bar-Chart.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes, it is good enough.

2.5. Would you like to work again with Clear Flow Matrix?

Yes.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

2 weeks is comfortably and one week is tight schedule. 2 weeks is better.

2.7. Does a “one-week-duration” (to manage the schedule of a project) work for you?

Yes, but two weeks is better.

2.8. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Not much.
Once, or twice.

2.9. Have you seen any productivity improvement since the Clear Flow Matrix was introduced in this project?

A few improvement.

2.10. Is the sequence of work logical in the Clear Flow Matrix?

Yes.

2.11. Have you seen any decrease of unnecessary (crew) movement since the implementation of the Clear Flow Matrix?

Yes, kind of.

2.12. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.13. Do you often have workers work overtime on this project? Has the overtime decreased since Clear Flow Matrix was initiated in this project?

Not much. Not decreased.

2.14. Does the Clear Flow Matrix help you with the crew size? How?

No.

2.15. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

No difference.

2.16. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

No.

2.17. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions to the schedule? Has the Clear Flow Matrix helped with changes in comparison to the previous scheduling method (CPM – Bar Charts).

2.18. Since the Clear Flow Matrix was introduced on this project has the rework increased, decreased or remained the same?

Remained the same.

In general matrix is good. Easier to understand, mainly for those who do not speak English.

The Clear flow gives me flexibility to work ahead. Weather varies how fast you can move.

Foreman Superintendent Questionnaire – Foreman 19

1. General Information

1.1. Type of Project: *Multifamily Apartments*

1.2. What type of work are you performing in this project?

Trim and Hardware

1.3. How long have you been working in this job?

5 months

1.4. How many men are in your crew?

5 men

2. Clear Flow Matrix Evaluation

2.1. You have worked on this project with two different methods of scheduling, CPM-Bar Charts and the Clear Flow Matrix. Do you see differences between these two methods? If yes, what are the main differences?

Lott Brothers coordinate better than the other company. The Clear Flow Matrix is better than CPM.

2.2. Do you think that the Clear Flow Matrix is a good construction scheduling tool?

Yes.

2.3. Does Clear Flow Matrix have a good visual presentation? Is the Matrix an intuitive tool? In comparison to CPM – Bar Charts, which one is easier to understand?

It is easy to understand. However, Bar-Chart is easier to understand.

2.4. Do you think that the Clear Flow Matrix provides enough detail to be a good scheduling tool?

Yes.

2.5. Would you like to work again with Clear Flow Matrix?

Yes.

2.6. The division of workspace in the Clear Flow Matrix is based on weekly intervals. This means that the activity in each area has one week to be performed. Do you think that in this project the workspace division fits comfortably within the period of one week?

Yes. It is good.

2.7. Does a “one-week-duration” (to manage the schedule of a project) work for you?

Yes.

2.8. How often have you had conflict with different trade crews working together in the same area? Have you had to make your crew wait, or move to another spot, or stop the work altogether, while waiting for the other crew to finish?

Never. Sometimes we had to wait. It has also happened in other projects in which the Bar Chart was used.

2.9. Have you seen any productivity improvement since the Clear Flow Matrix was introduced in this project?

Not really.

2.10. Is the sequence of work logical in the Clear Flow Matrix?

Yes.

2.11. Have you seen any decrease of unnecessary (crew) movement since the implementation of the Clear Flow Matrix?

NO, it has remained the same.

2.12. Does your crew often spend time waiting because you do not know where your crew is supposed to be working?

No.

2.13. Do you often have workers work overtime on this project? Has the overtime decreased since Clear Flow Matrix was initiated in this project?

No. No

2.14. Does the Clear Flow Matrix help you with the crew size? How?

Yes. Because it is clear to understand the future jobs that are coming to perform.

2.15. Does the Clear Flow Matrix help the coordination of resources (crew, equipment and material) within this project and also within other projects?

Yes.

2.16. Have you seen changes or disruptions in this project? What type of changes? How have you dealt with that?

No. No also in other projects.

2.17. How do you evaluate the ability of the Clear Flow Matrix to accommodate changes or disruptions to the schedule? Has the Clear Flow Matrix helped with changes in comparison to the previous scheduling method (CPM – Bar Charts)?

2.18. Since the Clear Flow Matrix was introduced on this project has the rework increased, decreased or remained the same?

Remained the same.

References

Bertelsen, S. (2004). Contruction Management In a Complexity Perspective. *1st International SCRI Symposium*, (pp. 1-12). University of Salford, UK.

Bertelsen, S., & Koskela, L. (2002). Managing the Three Aspects of Production in Construction. *IGLC-10*, (pp. 1-10). Gramado, Brazil.

Bertelsen, S., Henrich, G., Koskela, L., & Rooke, J. (2007). Construction Physics. *15th Anual Conference in the International Group for Lean Construction, ,* (pp. 1-14). Lansing, MI.

Birrell, G. (1980). Construction Planning - Beyond the Critical Path. *Journal of the Construction Division - ASCE, 106(3)*, 389-407.

Bolviken, T., Aslesen, S., & Koskela, L. (2015). What Is a Good Plan? *23rd Annual Conference of the International Group for Lean Construction,* (pp. 93-102). Perth, Australia.

Construction Industry Institute (CII). (2005). *Lean Principles in Construction - Research Summary 191-1.* Austin, Texas.

Construction Industry Institute (CII). (2005). *Making Zero Rework a Reality.* Research Summary 203-1.

Faloughi, M., Linnik, M., Murphy, D., & Frandson, A. (2015). WIP Design in Construction Project Using Takt Time Planning. *23rd Ann. Conf. International Group for Lean Construction* , (pp. 163-172). Perth, Australia.

Fayek, A., Dissanayake, M., & Campero, O. (2003). Measuring and Classifying Construction Field Rework: A Pilot Study. *Construction Owners Association of Alberta (COAA)* , (pp. 1-18).

Goldratt, E. (1997). *Critical Chain.* New York: Grower Publishing.

Goldratt, E., & Cox, J. (2004). *The Goal: The process of ongoing improvement.* Great Barrington, MA: North River Press.

Gong, J., Borcherding, J., & Caldas , C. (2011). Effectiveness of Craft Utilization in Construction Projects. *Construction Management and Economics 29 (7)*, 737-751.

Gonj, J., Borcherding, J., & Caldas, C. (2010). Assessment of direct work utilization at the workface in the US Construction Industry (1972-2008). *Construction Research Congress 2010: Innovation for Reshaping Construction Practice,* (pp. 960-969).

Henrich, G. T. (2005). Context of Production Control in Construction. *Annual Conference on Lean Construction,* (pp. 189-198). Sydney .

Henrich, G., & Koskela, L. (2006). Whay Does Production Management Fail in Construction? *6th International Postgraduate Research Conference-BuHu-,* (pp. 1-9). Delft, Netherlands.

Kalsaas, B., & Bolviken, T. (2010). The Flow of Work in Construction: A Conceptual Discussion. *18 th Annual Conference of the International Group for Lean*, (pp. 52-62). Haifa, Israel.

Kalsaas, B., Skaar, J., & Thorstensen, R. T. (2015). Pull vs. Push in Construction Work Informed by Last Planner. *23rd Ann. Conf. of the Int'l. Group for Lean Construction*, (pp. 103-112). Perth.

Koskela, L. (1992). *Application of the New Production Philosophy to Construction.* Center for Integrated Facility Engineering CIFE.

Koskela, L. (1999). Management of Production in Construction: A Theoretical View. *7th Annual Conference of the International Group for Lean Construction* , (pp. 241-252). Berkeley, Californa.

Koskela, L. (2000). *An Exploration Towards a Production Theory and Its Application to Construction.* Technical Research Centre of Finland: VTT Publications.

Koskela, L., & Howell, G. (2002). The Theory of Project Management: Explanation to novel methods. *Proceedings IGLC-10*, (pp. 1-11). Gramado, Brazil.

Koskela, L., & Howell, G. (2002). The Underlying Theory of Project Management is Obsolote. *PMI Research Conference*, (pp. 293-202).

Liou, W., & Borcherding, J. (1986). Work sampling can predict unit rate productivity. *Constr. Engrg. and Mgmt., ASCE 112(1)*, 90-103.

Little, J. D. (1961). A Proof for the Queuing Formula: L =λ W. *Operations Research, Vol.9, No.3*, 383-387.

Modig, N., & Åhlström, P. (2016). *This is Lean.* Stockholm: Rheologica Publishing.

O'Brien, W. J. (1998). *Capcity Costing Approaches for Construction Supply Chain Management*, Doctoral Dissertation, Stanford Unversity, 190 pages.

O'Brien, W. J. (2000). Multi-Project Resource Allocation: Parametric Models and Managerial Implications. *Proceedings of the Eighth Annual Conference of the International Group for Lean Construction*, (p. 11 pages). University of Sussex, Brighton, UK.

O'Connor, J., & Tucker, L. (1986). Industrial project constructability improvement. *J. Constr. Eng. Management, 112(1)*, 69-82.

Oglesby, C., Parker, H., & Howell, G. (1989). *Productivity Improvement in Construction.* New York: McGraw-Hill Book.

Parker, H. W., & Oglesby, C. H. (1972). *Mehtods Improvement for Construction.* United States of America: McGraw-Hill.

Rowley, J. (2014). Designing and using research questionnaires. *Management Research Review, Vol. 37 Issue: 3*, 308-330.

Sacks, R. (2016). What Constitutes Good Production Flow in Construction? *Construction Management and Economics 34 (9)* , 641-656.

Sacks, R., Seppaenen, O., Priven, V., & Savosnick, J. (2017). Construction Flow Index: A Metric of Production Flow Quality in Construction. *Construction Management and Economics 35:1-2*, 45-63.

Seed, W. R. (2015). *Transforming design and construction: a framework for change.* Arlington.

Shigeo, S. (1989). *A Study of the Toyota Production System.* Boca Raton, London and New York: Taylor and Francis Group.

Shim, E. (2011). Impacts of matched batch sizes on time reduction in construction projects. *28th International Symposium on Automation and Robotics in Construction.* Seoul, South Korea.

Thomas, R., Horman, M., Ubiraci, d., & Zavrski, I. (2002). Reducing Variability to Improve Performance as a Lean Construction Principle. *Journal of Construction Engineering and Management 128(2)*, 144-154.

Thomas, R., Riley, D., & Sinh, S. (2006). Fundamental Principles for Avoiding Congested Work Areas—A Case Study. *Practice Periodical on Structural Design and Construction ASCE 11(4)*, 197-205.

Tommelein, I. (1998). Pull Driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique. *ASCE Journal of Construction Engineering and Management, 124 (4)*, pp. 279-288.

Wang, L., & Leite, F. (2016). Formalized knowledge representation for spatial conflict coordination of mechanical, eletrical and plumbing (MEP) systems in new building projects. *Automation in Construction*, 20-26.

Wernicke, B., & Ledelow, H. (2016). Foundation for Balancing Resources and Flow Efficiency in Industrialized Construction. *International Conference on Construction and Real Estate Management 2016 -ICREM*, (pp. 103-110). Copenhagen.

Zhang, J., Eastham, D., & Bernold, L. (2005). Waste-Based Management in Residential Construction. *Journal of Construction Engineering and Management, ASCE, 131(4)*, 423-430.